BULLETIN 1724E-200

DESIGN MANUAL FOR HIGH VOLTAGE TRANSMISSION LINES

U.S. DEPARTMENT OF AGRICULTURE

RURAL UTILITIES SERVICE

ELECTRIC STAFF DIVISION

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UNITED STATES DEPARTMENT OF AGRICULTURE
Rural Utilities Service

BULLETIN 1724E-200

SUBJECT: **Design Manual for High Voltage Transmission Lines**

TO: All Electric Borrowers, Consulting Engineers, and Agency Electric Staff

EFFECTIVE DATE: Date of Approval

OFFICE OF PRIMARY INTEREST: Transmission Branch, Electric Staff Division

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http://www.usda.gov/rus/electric/bulletins.htm

PURPOSE: This guide publication is a reference containing fundamental engineering guidelines and basic recommendations on structural and electrical aspects of transmission line design, as well as explanations and illustrations. The many cross-references and examples should be of great benefit to engineers performing design work for Agency borrower transmission lines. The guide should be particularly helpful to relatively inexperienced engineers beginning their careers in transmission line design.

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ABBREVIATIONS

(See Appendix L for Engineering Symbols and Abbreviations)

AAAC	All Aluminum Alloy Conductor
AAC	All Aluminum Conductor
AACSR	Aluminum Alloy Conductor Steel Reinforced
AC	Alternating Current
ACCR	Aluminum Conductor Composite Reinforced
ACAR	Aluminum Conductor Alloy Reinforced
ACCC/TW	Aluminum Conductor, Composite Core, Trapezoidal Wire
ACSR	Aluminum Conductor Steel Reinforced
ACSS	Steel Supported Aluminum Conductor
ACSR/AW	Aluminum Conductor Steel Reinforced/Aluminum Clad Steel Reinforced
ACSR/SD	Aluminum Conductor Steel Reinforced/Self Damping
ACSR/TW	Aluminum Conductor Steel Reinforced/Trapezoidal Wire
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
AWAC	Aluminum Clad Steel, Aluminum Conductor
AWG	American Wire Guage
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
CADD	Computer-Aided Design and Drafting
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
COE	Corps of Engineers
DOE	Department of Energy
EPA	Environmental Protection Agency
EHV	Extra High Voltage
EIS	Environmental Impact Statement
EI&W	Extreme Ice & Concurrent Wind
EPRI	Electric Power Research Institute

ABBREVIATIONS

(continued from previous page)
(See Appendix L for Engineering Symbols and Abbreviations)

Eq.	Equation
FAA	Federal Aviation Agency
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FHA	Federal Highway Administration
FLPMA	Federal Land Policy and Management Act
FS	Forest Service
FWS	Fish and Wildlife Service
GIS	Geographic Information System
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronics Engineers, Inc.
LF	Load Factor
LWCF	Land and Water Conservation Fund Act
M&E	Mechanical and Electrical
MCOV	Maximum Continuous Over Voltage
MOR	Modulus of Rupture
MOV	Metal Oxide Varistor
NEPA	National Environmental Protection Act
NESC	National Electrical Safety Code
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
NRCS	Natural Resource Conservation Service
OHGW	Overhead Ground Wire
PL	Public Law
Psf	Pounds per square foot
RI	Radio Interference
RSL	Residual Static Load
REA	Rural Electrification Administration
ROW	Right-of-Way
RTK-GPS	Real Time Kinematic-Global Positioning System
RUS	Rural Utilities Service
SHPO	State Historical Preservation Officers
SML	Specified Mechanical Load
SPCC	Spill Prevention Control and Countermeasure
SYP	Southern Yellow Pine
T2	Twisted Pair Aluminum Conductor
T&D	Transmission and Distribution
TIN	Triangular Irregular Network
TVI	Television Interference
TW	Trapezoidal Wire
USC	United States Code
USDA	United States Department of Agriculture
USDI	United States Department of the Interior
USGS	United States Geological Survey

FOREWORD

Numerous references are made to tables, figures, charts, paragraphs, sections, and chapters. Unless stated otherwise, the tables, figures, charts, etc. referred to are found in this bulletin. When the reference is not in this bulletin, the document is identified by title and source. Any reference to agency means Rural Utilities Service.

ACKNOWLEDGEMENTS

Figures 9-6 and 9-7 of this bulletin are reprinted from IEEE Std 524-1992, "IEEE Guide to the Installation of Overhead Transmission Line Conductors, Copyright 1992 by IEEE. The IEEE disclaims any responsibility or liability resulting from the placement and use in the described manner.

Figures 4-2, 4-4, 5-2, 5-5 and 11-1 and the table on reference heights (page 4-3) of this bulletin are reprinted from IEEE/ANSI C2-2007, National Electrical Safety Code, Copyright 2007 by IEEE. The IEEE disclaims any responsibility or liability resulting from the placement and use in the described manner.

Figures 11-2a to 11-2e, 11-3a to 11-3f, and Tables E-2 and E-3 of this bulletin are reprinted from ASCE7-05, "Minimum Design Loads for Buildings and Other Structures," American Society of Civil Engineers, Copyright 2005. For further information, refer to the complete rest of the manual (http://www.pubs.asce.org/ASCE7.html?99991330).

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1. GENERAL

1.1 Purpose: The primary purpose of this bulletin is to furnish engineering information for use in designing transmission lines. Good line design should result in high continuity of service, long life of physical equipment, low maintenance costs, and safe operation.

1.2 Scope: The engineering information in this bulletin is for use in design of transmission lines for voltages 230 kV and below. Much of this document makes use of standard Rural Utilities Service (referred to as the agency) structures and assemblies in conjunction with data provided in this bulletin. Where nonstandard construction is used, factors not covered in this bulletin may have to be considered and modification to the design criteria given in this bulletin may be appropriate.

Since the agency program is national in scope, it is necessary that designs be adaptable to various conditions and local requirements. Engineers should investigate local weather information, soil conditions, operation of existing lines, local regulations, and environmental requirements and evaluate known pertinent factors in arriving at design recommendations.

1.3 National Electrical Safety Code (NESC): This bulletin is based on the requirements of the 2007 edition of the National Electrical Safety Code. In accordance with the Code of Federal Regulations 7 CFR Part 1724, agency financed lines are to be a minimum of Grade B construction as defined in the NESC. However, since the NESC is a safety code and not a design guide, additional information and design criteria are provided in this bulletin as guidance to the engineer.

The NESC may be purchased from the Institute of Electrical and Electronics Engineers (IEEE) Operations Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331 or at the following website:

http://standards.ieee.org/nesc

1.4 Responsibility: The borrower is to provide or obtain all engineering services necessary for sound and economical design. Due concern for the environment in all phases of construction and cleanup should be exercised.

1.5 Environmental Regulations: Agency environmental regulations are codified in 7 CFR Part 1794, "Environmental Policies and Procedures." These regulations reference additional laws, regulations and Executive Orders relative to the protection of the environment.

The Code of Federal Regulations may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

Agency environmental regulations may be found on the following website:

http://www.usda.gov/rus/electric/regs/index.htm

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2. TRANSMISSION LINE DOCUMENTATION

2.1 Purpose: The purpose of this chapter is to provide information regarding design documentation for transmission lines financed by the Rural Utilities Service.

2.2 General: Policy and procedures pertaining to construction of transmission lines by agency electric borrowers are codified in 7 CFR 1724, “Electric Engineering, Architectural Services and Design Policies and Procedures” and 7 CFR 1726, "Electric System Construction Policies and Procedures" (http://www.usda.gov/rus/electric/regs/index.htm). The requirements of 7 CFR 1726 apply to the procurement of materials and equipment for use by electric borrowers and to construction of the electric system if the material, equipment, and construction are financed, in whole or in part, with loans made or guaranteed by the Rural Utilities Service.

2.3 Design Data Summary: When design data is required by the agency, a design data summary (or its equivalent) should be submitted. Engineering design information includes design data, sample calculations, and plan-profile drawings. A ‘Transmission Line Design Data Summary Form’, which is included in Appendix A of this bulletin, has been prepared to aid in the presentation of the design data summary. A suggested outline in Appendix A indicates information that should be considered when preparing a design data summary. Appendix A also highlights information which should be included in the design data submitted to the agency when computer software has been used in the design.

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3. TRANSMISSION LINE LOCATION, ENGINEERING SURVEY AND RIGHT-OF-WAY ACTIVITIES

3.1 Route Selection: Transmission line routing requires a thorough investigation and study of several different alternate routes to assure that the most practical route is selected, taking into consideration the environmental criteria, cost of construction, land use, impact to public, maintenance and engineering considerations.

To select and identify environmentally acceptable transmission line routes, it is necessary to identify all requirements imposed by State and Federal legislation. Environmental considerations are generally outlined in agency Bulletin 1794A-601, "Guide for Preparing Environmental Reports for Electric Projects That Require Environmental Assessments." State public utility commissions and departments of natural resources may also designate avoidance and exclusion areas which have to be considered in the routing process.

Maps are developed in order to identify avoidance and exclusion areas and other requirements which might impinge on the line route. Ideally, all physical and environmental considerations should be plotted on one map so this information can be used for route evaluation. However, when there are a large number of areas to be identified or many relevant environmental concerns, more than one map may have to be prepared for clarity. The number of maps engineers need to refer to in order to analyze routing alternatives should be kept to a minimum.

Typical physical, biological and human environmental routing considerations are listed in Table 3-1. The order in which considerations are listed is not intended to imply any priority. In specific situations, environmental concerns other than those listed may be relevant. Suggested sources for such information are also included in the table. Sources of information include the United States Geological Service (USGS), Federal Emergency Management Agency (FEMA), United States Department of the Interior (USDI), United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS) and numerous local and state agencies.

For large projects, photogrammetry is contributing substantially to route selection and design of lines. Preliminary corridor location is improved when high altitude aerial photographs or satellite imagery are used to rapidly and accurately inventory existing land use. Once the preferred and alternative corridors have been identified, the engineer should consult USGS maps, county soil maps, and plat and road maps in order to produce small scale maps to be used to identify additional obstructions and considerations for the preferred transmission line.

On smaller projects, the line lengths are often short and high altitude photograph and satellite imagery offer fewer benefits. For such projects, engineers should seek existing aerial photographs. Sources for such photographs include county planning agencies, pipeline companies, county highway departments, and land development corporations. A preliminary field survey should also be made to locate possible new features which do not appear on USGS maps or aerial photographs.

As computer information systems become less expensive and easier to use, electric transmission utilities are using Geographic Information Systems(GIS) to automate the route identification process. GIS technology enables users to easily consolidate maps and attribute information from various sources and to efficiently analyze what has been collected. When used by routing experts, automated computer processes help standardize the route evaluation and selection process, promote objective quantitative analysis and help users select defendable routes. GIS tools have proven very beneficial to utilities whose goals are to minimize impact on people and the natural environment while selecting a constructible, maintainable and cost effective route.

Final route selection, whether for a large or small project, is a matter of judgment and requires sound evaluation of divergent requirements, including costs of easements, cost of clearing, and ease of maintenance as well as the effect a line may have on the environment. Public relations and public input are necessary in the corridor selection and preliminary survey stages.

TABLE 3-1
LINE ROUTING CONSIDERATIONS

Physical	**Sources**
• Highways	USGS, state & county highway department maps
• Streams, rivers, lakes	USGS, Army Corps of Engineers, flood insurance maps
• Railroads	USGS, railroad
• Airstrips	USGS, Federal Aviation Administration (FAA)
• Topography (major ridge lines, floodplains, etc.)	USGS, flood insurance maps (FEMA), Army Corps of Engineers
• Transmission lines & distribution lines	USGS, local utility system maps
• Pipelines,(water, gas, sewer), underground Electric	USGS, local utility system maps
• Occupied buildings	Local tax maps, land use maps, local GIS maps
Biological	**Sources**
• Woodlands	USGS, USDA - Forest Service,
• Wetlands	USGS, Army Corps of Engineers, USDA National Conservation Resource Service, USDI Fish and Wildlife Service
• Waterfowl, wildlife refuge areas, endangered species & critical Habitat Areas	USDI - Fish and Wildlife Service, State Fish and Game Office
Human Environmental	**Sources**
• Rangeland	USGS aerial survey, satellite mapping, county planning agencies, state planning agencies, state soil conservation service, mining bureau, U.S. Bureau of Land Management, NRCS
• Cropland	
• Urban development	
• Industrial development	
• Mining areas	
• Recreation or aesthetic areas, national parks, state and local parks	
• Prime or unique farmland	USGS, soil surveys, USDA - NRCS, state department of agriculture, county extension agent
• Irrigation (existing & potential)	Irrigation district maps, applications for electrical service, aerial survey, state departments of agriculture and natural resources, water management districts
• Historic and archeological sites	National Register of Historic Sites (existing), state historic preservation officer , state historic and archeological societies
• Wild and scenic rivers	USGS maps, state maps, state department of natural resources, Department of Interior
Other	**Sources**
• Federal, state and county controlled lands	USGS, state maps, USDI Park Service, Bureau of Land Management, state department of natural resources, county maps, etc.

3.2 Reconnaissance and Preliminary Survey: Once the best route has been selected and a field examination made, aerial photos of the corridor should be reexamined to determine what corrections will be necessary for practical line location. Certain carefully located control points should then be established from an aerial reconnaissance. Once these control points have been made, a transit line using stakes with tack points should be laid in order to fix the alignment of the line. A considerable portion of this preliminary survey usually turns out to be the final location of the line.

In many instances, after route has been selected and a field examination made, digital design data on a known coordinate system like State Plane is used for centerline alignment and profile. This alignment is provided to surveyors in a universal drawing file format. The surveyors then convert it to a format used by their field recording equipment. Once the project location is known, base control monuments are established along the route at 2 to 5 mile intervals, depending on topography, with static Global Positioning System (GPS) sessions from known horizontal and vertical control monuments. GPS equipment and radio transmitter equipment occupying the base monuments broadcast a corrected signal to roving GPS unit(s). These GPS units, with the use of an on-board field computer, allow any point or any line segment along the route to be reproduced in the field. The roving unit can be used to locate and verify wire heights at crossings, unmarked property lines or any routing concerns that may come up locally. The equipment can also be used to establish centerline points in open areas so that conventional survey equipment can be used to mark the line in wooded areas for clearing purposes. Once the right-of-way (ROW) has been cleared, all structures can be staked with the Real Time Kinematic-Global Positioning System (RTK-GPS) equipment. Since this entire process uses data of a known mapping plane, any position along the route can be converted to various formats and used within databases.

3.3 Right-of-Way: A right-of-way agent (or borrower's representative) should precede the preliminary survey party in order to acquaint property owners with the purpose of the project, the survey, and to secure permission to run the survey line. The agent or surveyor should also be responsible for determining property boundaries crossed and for maintaining good public relations. The agent should avoid making any commitments for individual pole locations before structures are spotted on the plan and profile sheets. However, if the landowner feels particularly sensitive about placing a pole in a particular location along the alignment, then the agent should deliver that information to the engineer, and every reasonable effort should be made by the engineer to accommodate the landowner.

As the survey proceeds, a right-of-way agent should begin a check of the records (for faulty titles, transfers, joint owners, foreclosed mortgages, etc.) against the ownership information ascertained from the residents. This phase of the work requires close coordination between the engineer and the right-of-way agent. At this time, the right-of-way agent also has to consider any access easements necessary to construct or maintain the line.

Permission may also have to be obtained to cut danger trees located outside inside the right-of-way. Costly details, misuse of survey time and effort, and misunderstanding on the part of the landowners should be avoided.

3.4 Line Survey: Immediately after the alignment of a line has been finalized to the satisfaction of both the engineer and the borrower, a survey should be made to map the route of the line. Based on this survey, plan-profile drawings will be produced and used to spot structures.

Long corridors can usually be mapped by photogrammetry at less cost than equivalent ground surveys. The photographs will also contain information and details which could not otherwise be discovered or recorded. Aerial survey of the corridor can be accomplished rapidly, but proper conditions for photography occur only on a comparatively few days during the year. In certain

areas, photogrammetry is impossible. It cannot be used where high conifers conceal the ground or in areas such as grass-covered plains that contain no discernible objects. Necessary delays and overhead costs inherent in air mapping usually prevent their use for short lines.

When using photogrammetry to develop plan-profile drawings, proper horizontal and vertical controls should first be established in accordance with accepted surveying methods. From a series of overlapping aerial photographs, a plan of the transmission line route can be made. The plan may be in the form of an orthophoto or it may be a planimetric map (see Chapter 10). The overlapping photos also enable the development of profile drawings. The tolerance of plotted ground elevations to the actual ground profile will depend on photogrammetric equipment, flying height, and accuracy of control points.

Survey data can be gathered using a helicopter-mounted laser to scan existing lines and/or topography. Three dimensional coordinates of millions of points can be gathered while also taking forward and downward looking videos. These points can be classified into ground points, structure points and wire points.

If use of photogrammetry or laser-derived survey information for topographic mapping is not applicable for a particular line, then transit and tape or various electronic instruments for measuring distance should be used to make the route survey. This survey will generally consist of placing stakes at 100 foot intervals with the station measurement suitably marked on the stakes. It will also include the placement of intermediate stakes to note the station at property lines and reference points as required. The stakes should be aligned by transit between the hub stakes set on the preliminary survey. The survey party needs to keep notes showing property lines and topographic features of obstructions that would influence structure spotting. To facilitate the location of the route by others, colored ribbon or strips of cloth should be attached at all fence crossings and to trees at regular intervals along the route (wherever possible).

As soon as the horizontal control survey is sufficiently advanced, a level party should start taking ground elevations along the center line of the survey. Levels should be taken at every 100 foot stations and at all intermediate points where breaks in the ground contour appear. Wherever the ground slopes more than 10 percent across the line of survey, side shots should be taken for a distance of at least 10 feet beyond the outside conductor's normal position. These elevations to the right and left of the center line should be plotted as broken lines. The broken lines represent side hill profiles and are needed, when spotting structures, to assure proper ground clearance under all conductors, and proper pole lengths and setting depths for multiple-pole structures.

3.5 Drawings: As soon as the route survey has been obtained, the plan and profile should be prepared. Information on the plan and profile should include alignment, stationing, calculated courses, fences, trees, roads, ditches, streams, and swamps. The vertical and plan location of telecommunications, transmission and other electric lines should be included since they affect the proposed line. The drawings should also show railroads and river crossings, property lines, with the names of the property owners, along with any other features which may be of value in the right-of-way acquisition, design, construction, and operation of the line. Chapter 10 discusses structure spotting on the plan-profile drawings.

Structure spotting should begin after all of the topographic and level notes are plotted on the plan and profile sheets. Prints of the drawings should be furnished to the right-of-way agent for checking property lines and for recording easements. One set of prints certified as to the extent of permits, easements, etc. that has been secured by the borrower should be returned to the engineer.

3.6 Rerouting: During the final survey, it may be necessary to consider routing small segments of the line due to the inability of the right-of-way agent to satisfy the demands of property

owners. In such instances, the engineer should ascertain the costs and public attitudes towards all reasonable alternatives. The engineer should then decide to either satisfy the property owner's demands, relocate the line, initiate condemnation proceedings, or take other action as appropriate. Additional environmental review may also be required.

3.7 Clearing Right-of-Way: The first actual work to be done on a transmission line is usually clearing the right-of-way. When clearing, it is important that the environment be considered. Environmental commitments/mitigations should be included in the construction contracts. It is also important that the clearing be done in such a manner that will not interfere with the construction, operation or maintenance of the line. In terrain having heavy timber, prior partial clearing may be desirable to facilitate surveying. All right-of-way for a given line should be secured before starting construction. See Chapter 5 for a discussion of right-of-way width.

3.8 Permits, Easements, Licenses, Franchises, and Authorizations: The following list of permits, easements, licenses, franchises, and authorizations that commonly need to be obtained is not meant to be exhaustive.

Private property	Easement from owner and permission to cut danger trees
Railroad	Permit or agreement
Highway	Permit from state/county/city
Other public bodies	Authorization
City, county or state	Permit
Joint and common use pole	Permit or agreement
Wire crossing	Permission of utility

Table 3-2 list required federal permits or licenses required and other environmental review requirements. The following abbreviations pertain to Table 3-2:

BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
COE	Corps of Engineers
DOE	Department of Energy
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FAA	Federal Aviation Agency
FERC	Federal Energy Regulatory Commission
FHA	Federal Highway Administration
FLPMA	Federal Land Policy and Management Act
FS	Forest Service
FWS	Fish and Wildlife Service
LWCF	Land and Water Conservation Fund Act
NEPA	National Environmental Protection Act
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
PL	Public Law
SHPO	State Historical Preservation Officer
SPCC	Spill Prevention Control and Countermeasure
USC	United States Code

TABLE 3-2
SUMMARY OF POTENTIAL MAJOR FEDERAL PERMITS OR LICENSES THAT MAY BE REQUIRED
And other environmental review requirements for transmission line construction and operation

Issue	Action Requiring Permit, Approval, or Review	Agency	Permit, License, Compliance or Review	Relevant Laws and Regulations
NEPA (National Environmental Protection Act) Compliance	Federal; Action to grant right-of-way across land under Federal jurisdiction	Lead Agency –	EIS and Record of Decision	NEPA (42 USC 4321), CEQ (40 CFR 1500-1508). DOE NEPA implementing Regulations (10 CFR to 1021)
Right-of-Way Across Land Under Federal Management	Preconstruction surveys; construction, operation, maintenance, and abandonment	Bureau of Land Management (BLM)	Right-of-way grant and special use permit	Federal Land Policy and Management Act (FLPMA) of 1976 (PL 94-579) 43 USC 1761-1771 43 CFR 2800
		Bureau of Indian Affairs (BIA), tribe	Right-of-way grant across American Indian lands	25 CFR 169
		Forest Service (FS)	Special use authorization permit or easement	36 CFR 251
		National Park Service (NPS)	Authorization to cross National Park Service lands	18 USC, 36 CFR 14
		Fish and Wildlife Service (FWS)	Special use permit for crossing a national wildlife refuge	50 CFR 25
	"Conversion of use" for a use other than recreation on lands reserved with Land and Water Conservation Fund Act (LWCF) monies	NPS	Review of transmission line corridor to identify conflicts with recreational areas	Land and Water Conservation Fund Act PL 88-578, Section 6(f)(3)
	Construction, operation, maintenance, and abandonment of transmission line across or within highway rights-of-way	Federal Highway Administration (FHA)	Permits to cross Federal Aid Highway; 4 (f) compliance	Department of Transportation Act 23 CFR 1.23 and 1.27 23 USC 116, 123, and 315 23 CFR 645 23 CFR 771
Biological Resources	Grant right-of-way by federal land-managing agency	FWS	Endangered Species Act compliance by federal land-managing agency and lead agency	Endangered Species Act of 1973 as amended (16 USC 1531 et seq)
	Protection of migratory birds	FWS	Compliance	Migratory Bird Treaty Act of 1918 16 USC 703-712 50 CFR Ch 1
	Protection of bald and golden eagles	FWS	Compliance	Bald and Golden Eagle Protection Act of 1972 (16 USC 668)
Paleontological Resources	Ground disturbance on federal land or federal aid project	BLM	Compliance with BLM mitigation and planning standards for paleontological resources of public lands	FLPMA of 1976 (43 USC 1701-1771) Antiquities Act of 1906 (16 USC 431-433)

TABLE 3-2 (Continued)
SUMMARY OF POTENTIAL MAJOR FEDERAL PERMITS OR LICENSES THAT MAY BE REQUIRED
And other environmental review requirements for transmission line construction and operation

Issue	Action Requiring Permit, Approval, or Review	Agency	Permit, License, Compliance or Review	Relevant Laws and Regulations
Ground Disturbance and Water Quality Degradation	Construction sites with greater than five acres of land disturbance	Environmental Protection Agency (EPA)	Section 402 National Pollutant Discharge Elimination System (NPDES) General Permit for Storm Water Discharges from Construction Activities	Clean Water Act (33 USC 1342)
	Construction across water resources	Army Corps of Engineers (COE)	General easement	10 USC 2668 to 2669
	Crossing 100-year floodplain, streams, and rivers	COE	Floodplain use permits	40 USC 961
	Construction in or modification of floodplain	Federal lead agency	Compliance	Executive Order 11988 Floodplains
	Construction or modification of wetlands	Federal lead agency	Compliance	Executive Order 11990 Wetlands
	Potential discharge into water of the state (including wetlands and washes)	COE (and states); EPA on tribal lands	Section 401 permit	Clean Water Act (33 USC 1344)
	Discharge of dredge or fill material to watercourse	COE; EPA on tribal lands	404 Permit (individual or nationwide)	Clean Water Act (33 USC 1344)
	Placement of structures and construction work in navigable waters of the U.S	COE	Section 10 permit	Rivers and Harbors Act of 1899 (33 USC 403)
	Protection of all rivers included in the National Wild and Scenic Rivers System	Affected land-managing agencies	Review by permitting agencies	Wild and Scenic Rivers Act (PL 90- 542) (43 CFR 83.50)
	Potential pollutant discharge during construction, operation, and maintenance	EPA	Spill Prevention Control and Countermeasure (SPCC) plan for substations	Oil Pollution Act of 1990 (40 CFR 112)
Air Traffic	Location of towers in regards to airport facilities and airspace	Federal Aviation Administration (FAA)	A “No-hazard Declaration” required if structure is more than 200 feet in height	FAA Act of 1958 (49 USC 1501) (14 CFR 77)
			Section 1101 Air Space Permit for air space construction clearance	FAA Act of 1958 (49 USC 1501) (14 CFR 77)

TABLE 3-2 (Continued)
SUMMARY OF POTENTIAL MAJOR FEDERAL PERMITS OR LICENSES THAT MAY BE REQUIRED
And other environmental review requirements for transmission line construction and operation

Issue	Action Requiring Permit, Approval, or Review	Agency	Permit, License, Compliance or Review	Relevant Laws and Regulations
Cultural Resources	Disturbance of historic properties	Federal lead agency, State Historical Preservation Officers (SHPO), Advisory Council on Historic Preservation	Section 106 consultation	National Historic Preservation Act of 1966 (16 USC 470) (36 CFR Part 800)
	Excavation of archaeological resources	Federal land-managing agency	Permits to excavate	Archaeological Resources Protection Act of 1979 (16 USC 470aa to 470ee)
	Potential conflicts with freedom to practice traditional American Indian religions	Federal lead agency, Federal land-managing agency	Consultation with affected American Indians	American Indian Religious Freedom Act (42 USC 1996)
	Disturbance of graves, associated funerary objects, sacred objects, and items of cultural patrimony	Federal land-managing agency	Consultation with affected Native American group regarding treatment of remains and objects	Native American Graves Protection and Repatriation Act of 1990 (25 USC 3001)
	Investigation of cultural and paleontological resources	Affected land-managing agencies	Permit for study of historical, archaeological, and paleontological resources	Antiquities Act of 1906 (16 USC 432-433)
	Investigation of cultural resources	Affected land-managing agencies	Permits to excavate and remove archaeological resources on Federal lands; American Indian tribes with interests in resources must be consulted prior to issuance of permits	Archaeological Resources Protection Act of 1979 (16 USC 470aa to 470ee) (43 CFR 7)
	Protection of segments, sites, and features related to national trails	Affected land-managing agencies	National Trails Systems Act compliance	National Trails System Act (PL 90-543) (16 USC 1241 to 1249)
Rate regulation	Sales for resale and transmission services	Federal Energy Regulatory Commission (FERC)	Federal Power Act compliance by power seller	Federal Power Act (16 USC 792)

In cases where structures or conductors will exceed a height of 200 feet, or are within 20,000 feet of an airport, the nearest regional or area office of the FAA must be contacted. In addition, if required, FAA Form 7460-1, "Notice of Proposed Construction or Alteration," is to be filed. Care must also be given when locating lines near hospital landing pads, crop duster operations, and military bases.

4. CLEARANCES TO GROUND, TO OBJECTS UNDER THE LINE AND AT CROSSINGS

4.1 General: Recommended design vertical clearances for agency financed transmission lines of 230 kV and below are listed in the Tables 4-1 through 4-3. These clearances exceed the minimum clearances calculated in accordance with the 2007 edition of the NESC. If the 2007 edition has not been adopted in a particular locale, clearances and the conditions found in this chapter should be reviewed to ensure that they meet the more stringent of the applicable requirements.

Clearance values provided in the following tables are recommended design values. In order to provide an additional cushion of safety, recommended design values exceed the minimum clearances in the 2007 NESC.

4.2 Assumptions

4.2.1 Fault Clearing and Switching Surges: Clearances in tables 4-1, 4-2, 4-3, and 5-1 are recommended for transmission lines capable of clearing line-to-ground faults and voltages up to 230 kV. For 230 kV, the tables apply for switching surges less than or equal to 2.0; for higher switching surges on 230 kV transmission lines see the alternate clearance recommendations in the NESC.

4.2.2 Voltage: Listed in the chart that follows are nominal transmission line voltages and the assumed maximum allowable operating voltage for these nominal voltages. If the expected operating voltage is greater than the value given below, the clearances in this bulletin may be inadequate. Refer to the 2007 edition of the NESC for guidance.

Nominal Line-to-Line Voltage (kV)	Maximum Line-to Line Operating Voltage (kV)
34.5	*
46	*
69	72.5
115	121
138	145
161	169
230	242

*Maximum operating voltage has no effect on clearance requirements for these nominal voltages.

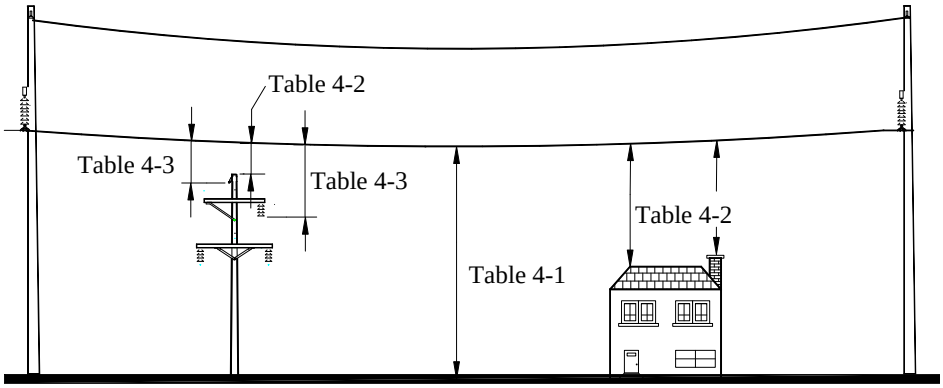

FIGURE 4-1: CLEARANCE SITUATIONS COVERED IN THIS CHAPTER

4.3 Design Vertical Clearance of Conductors: The recommended design vertical clearances under various conditions are provided in Table 4-1.

4.3.1 Conditions Under Which Clearances Apply: The clearances apply to a conductor at final sag for the conditions 'a' through 'c' listed below. The condition that produces the greatest sag for the line is the one that applies.

a. Conductor temperature of 32°F, no wind, with the radial thickness of ice for the applicable NESC loading district.

b. Conductor temperature of 167°F. A lower temperature may be considered where justified by a qualified engineering study. Under no circumstances should a design temperature be less than 120°F.

c. Maximum design conductor temperature, no wind. For high voltage bulk transmission lines of major importance to the system, consideration should be given to the use of 212°F as the maximum design conductor temperature.

According to the National Electric Reliability Council Criteria, emergency loading for lines of a system would be the line loads sustained when the worst combination of one line and one generator outage occurs. The loads used for condition "c" should be based on long range load forecasts.

Sags of overhead transmission conductors are predicted fairly accurately for normal operating temperatures. However, it has consistently been observed that sags for ACSR (Aluminum Conductor Steel Reinforced) conductors can be greater than predicted at elevated temperatures. If conductors are to be regularly operated at elevated temperatures, it is important that sag behavior be well understood. Current knowledge of the effects of high temperature operation on the long term behavior of conductors and associated hardware (splices, etc.) is probably limited; however, and a clear understanding of the issues involved is essential. The Electric Power Research Institute (EPRI) has prepared a report on the effects of high temperature conductor and associated hardware. [1]

The traditional approach in predicting ACSR conductor sag has been to assume that the aluminum and steel share only tension loads. But as conductor temperature rises, aluminum expands more rapidly than steel. Eventually the aluminum tension will reduce to zero and then go into compression. Beyond this point the steel carries the total conductor tension. These compressive stresses generally occur when conductors are operated above 176 °F to 200 °F. Greater sags than predicted at these elevated temperatures may be attributed to aluminum being in compression which is normally neglected by traditional sag and tension methods. AAC (All Aluminum Conductors) and AAAC (All Aluminum Alloy Conductor) or ACSR conductors having only one layer of aluminum or ACSR with less than 7 percent steel should not have significantly larger sags than predicted by these traditional methods at higher operating temperatures. [2]

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[1] *Conductor and Associated Hardware Impacts During High Temperature Operations – Issues and Problems, L. Shan and D. Douglass, Final Report, EPRI TR-109044, Electric Power Research Institute, Palo Alto, California, December, 1997.*

[2] *Conductor Sag and Tension Characteristics at High Temperatures, Tapani O. Seppa and Timo Seppa, The Valley Group, Inc., presented at the Southeastern Exchange Annual E/O Meeting, May 22, 1996, in Atlanta, GA.*

4.3.2 Altitude Greater than 3300 Feet: If the altitude of a transmission line (or a portion thereof) is greater than 3300 feet, an additional clearance as indicated in Table 4-1 must be added to the base clearances given.

4.3.3 Spaces and Ways Accessible to Pedestrians Only: Pedestrian-only clearances should be applied carefully. If it is possible for anything other than a person on foot to get under the line, such as a person riding a horse, the line should not be considered to be accessible to pedestrians-only and another clearance category should be used. It is expected that this type of clearance will be used rarely and only in the most unusual circumstances.

4.3.4 Clearance for Lines Along Roads in Rural Districts: If a line along a road in a rural district is adjacent to a cultivated field or other land falling into Category 3 of Table 4-1, the clearance-to-ground should be based on the clearance requirements of Category 3 unless the line is located entirely within the road right-of-way and is inaccessible to vehicular traffic, including highway right-of-way maintenance equipment. If a line meets these two requirements, its clearance may be based on the "along road in rural district" requirement. To avoid the need for future line changes, it is strongly recommended that the ground clearance for the line should be based on clearance over driveways. This should be done whenever it is considered likely a driveway will be built somewhere under the line. Heavily traveled rural roads should be considered as being in urban areas.

4.3.5 Reference Component and Tall Vehicles/Boats: There may be areas where it can be normally expected that tall vehicles/boats will pass under the line. In such areas, it is recommended that consideration be given to increasing the clearances given in Table 4-1 by the amount by which the operating height of the vehicle/boat exceeds the reference component. The reference component is that part of the clearance component which covers the activity in the area which the overhead line crosses.

For example, truck height is limited to 14 feet by state regulation, thus the reference component for roads is 14 feet. However, in northern climates sanding trucks typically operate with their box in an elevated position to distribute the sand and salt to icy roadways. The clearances in Table 4-1 are to be increased by the amount the sanding truck operating height exceeds 14 feet. In another example, the height of farm equipment may be 14 feet or more. In these cases, these clearances should be increased by the difference between the known height of the oversized vehicle and the reference height of 14 feet.

Reference heights for Table 4-1 are given below:

Item	Description	Reference height (feet)
1.0	Track rails	22.0
2.0	Roads, streets, alleys, etc	14.0
3.0	Residential driveways	14.0
4.0	Other lands traversed by vehicles	14.0
5.0	Spaces and ways--pedestrians only	8.0/10.0
6.0	Water areas--no sail boating	12.5
7.0	Water areas—sail boating	
	Less than 20 acres	16.0
	20 to 200 acres	30.0
	200 to 2000 acres	30.0
	Over 2000 acres	36.0
8.0	Areas posted for rigging or launching sailboats	See item 7.0

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For reference components to Table 4-2, see Appendix A, Table A-2b of the NESC.

4.3.6 Clearances Over Water: Clearances over navigable waterways are governed by the U.S. Army Corps of Engineers and therefore the clearances over water provided in Table 4-1 apply only where the Corps does not have jurisdiction.

4.3.7 Clearances for Sag Templates: Sag templates used for spotting structures on a plan and profile sheet should be cut to allow at least one foot extra clearance than given in Table 4-1, in order to compensate for minor errors and to provide flexibility for minor shifts in structure location.

Where the terrain or survey method used in obtaining the ground profile for the plan and profile sheets is subject to greater unknowns or tolerances than the one foot allowed, appropriate additional clearance should be provided.

4.4 Design Vertical Clearance of Conductors to Objects Under the Line (not including conductors of other lines): The recommended design vertical clearances to various objects under a transmission line are given in Table 4-2.

4.4.1 Conditions Under Which Clearances Apply: The clearances in Table 4-2 apply under the same loading and temperature conditions as outlined in section 4.3.1 of this chapter. See NESC Figures 234-1(a) and 234-1(b) and 234-1(c) for transition zones between horizontal and vertical clearance planes. See Chapter 5 for horizontal clearances.

4.4.2 Lines Over Buildings: Although clearances for lines passing over buildings are shown in Table 4-2, it is recommended that lines not pass directly over a building if it can be avoided.

4.4.3 Clearances to Rail Cars: The NESC has defined the clearance envelope around rail cars as shown in Figure 4-2 (NESC Figure 234-5):

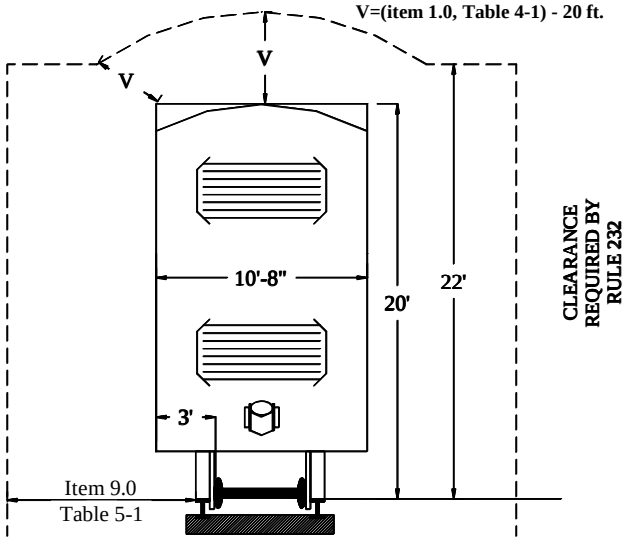

FIGURE 4-2: NESC FIGURE 234-5

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To simplify the design process, Figure 4-3, which defines the recommended clearances, may be used:

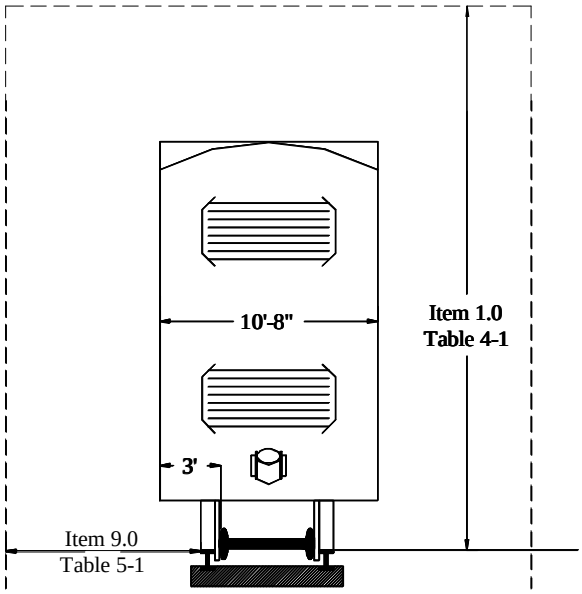

FIGURE 4-3: SIMPLIFIED CLEARANCE ENVELOPE

In cases where the base of the transmission line is below that of the railroad bed, the designer may be required to install taller poles or to offset further from the track (using the agency suggested approach) than is indicated by the NESC clearance envelope.

4.4.4 <u>Lines Over Swimming Pools</u>: Clearances over swimming pools are for reference purposes only. Lines should not pass over or within clearance 'A' of the edge of a swimming pool or the base of the diving platform. Clearance 'B' should be maintained in any direction to the diving platform or tower.

FIGURE 4-4: SWIMMING POOL CLEARANCES (See TABLE 4-2)
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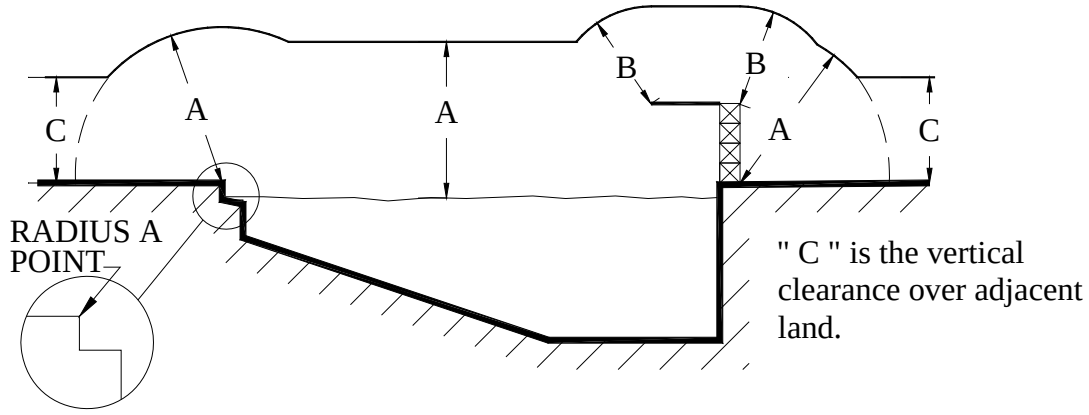

TABLE 4-1
RECOMMENDED DESIGN VERTICAL CLEARANCES OF CONDUCTORS ABOVE GROUND, ROADWAYS, RAILS, OR WATER SURFACE (in feet) (See Notes A, F & G)
(Applicable NESC Rules 232A, 232B, and Table 232-1)

Line conditions under which the NESC states vertical clearances shall be met (Calculations are based on Maximum Operating Voltage):

- 32°F, no wind, with radial thickness of ice, if any, specified in Rule 250B of the NESC for the loading district concerned.
- Maximum conductor temperature for which the line is designed to operate, with no horizontal displacement

Nominal Voltage, Phase to Phase (kV_{LL})		**34.5 & 46**	**69**	**115**	**138**	**161**	**230**
Max. Operating Voltage, Phase to Phase	(kV_{LL})	----	72.5	120.8	144.9	169.1	241.5
Max. Operating Voltage, Phase to Ground	(kV_{LG})	----	41.8	69.7	83.7	97.6	139.4
	NESC Basic Clear.(Note F)	Clearances in feet					
1.0 Track rails	26.5	29.2	29.7	30.6	31.1	31.5	32.9
2.0 Roads, streets, etc., subject to truck traffic	18.5	21.2	21.7	22.6	23.1	23.5	24.9
3.0 Driveways, parking lots, and alleys	18.5	21.2	21.7	22.6	23.1	23.5	24.9
4.0 Other lands cultivated etc., traversed by vehicles (Note B)	18.5	21.2	21.7	22.6	23.1	23.5	24.9
5.0 Spaces and ways accessible to pedestrians only (Note C)	14.5	17.2	17.7	18.6	19.1	19.5	20.9
6.0 Water areas – no sail boating	17.0	19.7	20.2	21.1	21.6	22.0	23.4
7.0 Water areas – sail boating suitable (Notes D & E)							
Less than 20 acres	20.5	23.2	23.7	24.6	25.1	25.5	26.9
20 to 200 acres	28.5	31.2	31.7	32.6	33.1	33.5	34.9
200 to 2000 acres	34.5	37.2	37.7	38.6	39.1	39.5	40.9
Over 2000 acres	40.5	43.2	43.7	44.6	45.1	45.5	46.9
8.0 Public or private land and water areas posted for rigging or launching sailboats (Note E)							
Less than 20 acres	25.5	28.2	28.7	29.6	30.1	30.5	31.9
20 to 200 acres	33.5	36.2	36.7	37.6	38.1	38.5	39.9
200 to 2000 acres	39.5	42.2	42.7	43.6	44.1	44.5	45.9
Over 2000 acres	45.5	48.2	48.7	49.6	50.1	50.5	51.9
ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE:							
Additional feet of clearance per 1000 feet of altitude above 3300 feet		.00	.02	.05	.07	.08	.12

TABLE 4-1
(continued from previous page)
RECOMMENDED DESIGN VERTICAL CLEARANCE OF CONDUCTORS ABOVE GROUND, ROADWAYS, RAILS, OR WATER SURFACE (in feet) (See Notes A, F & G)
(Applicable NESC Rules 232A, 232B, and Table 232-1

Notes:

(A) For voltages exceeding 98 kV alternating current to ground, or 139 kV direct current to ground, the NESC states that either the clearance shall be increased or the electric field, or the effects thereof, shall be reduced by other means, as required, to limit the current due to electrostatic effects to 5.0 milliampere (mA), rms, if the largest anticipated truck, vehicle or equipment under the line were short circuited to ground. The size of the anticipated truck, vehicle, or equipment used to determine these clearances may be less than but need not be greater than that limited by Federal, State, or local regulations governing the area under the line. For this determination, the conductors shall be at final unloaded sag at 120° F.

Fences and large permanent metallic structures in the vicinity of the line will be grounded in accordance with the owner's grounding units for the structure concerned to meet the 5.0 milliampere requirement. There should be adequate ground clearance at crossings and along the right-of-way to meet the minimum requirement of 5 mA due to the electrostatic field effects on the anticipated vehicles under the transmission line.

Consideration should be given to using the 5.0 mA rule to the conductor under maximum sag condition of the conductor.

(B) These clearances are for land traversed by vehicles and equipment whose overall operating height is less than 14 feet.

(C) Areas accessible to pedestrians only are areas where riders on horses or other large animals, vehicles or other mobile units exceeding 8 feet in height are prohibited by regulation or permanent terrain configurations or are not normally encountered nor reasonably anticipated. Land subject to highway right-of-way maintenance equipment is not to be considered as being accessible to pedestrians only.

(D) The NESC states that "for uncontrolled water flow areas, the surface area shall be that enclosed by its annual high-water mark. Clearances shall be based on the normal flood level; if available, the 10 year flood level may be assumed as the normal flood level. The clearance over rivers, streams, and canals shall be based upon the largest surface area of any one mile-long segment which includes the crossing. The clearance over a canal, river, or stream normally used to provide access for sailboats to a larger body of water shall be the same as that required for the larger body of water."

(E) Where the U.S. Army Corps of Engineers or the state, has issued a crossing permit, the clearances of that permit shall govern.

(F) The NESC basic clearance is defined as the reference height plus the electrical component for open supply conductors up to 22 kV_{L-G}.

(G) An additional 2.5 feet of clearance is added to the NESC clearance to obtain the recommended design clearances. Greater values should be used where survey methods to develop the ground profile are subject to greater unknowns. See Chapter 10, paragraph 10.3 of this bulletin.

TABLE 4-2
RECOMMENDED DESIGN VERTICAL CLEARANCES FROM OTHER SUPPORTING STRUCTURES (See Note B), BUILDINGS AND OTHER INSTALLATIONS (in feet)
(Applicable NESC Rules: 234A, 234B, 234C, 234D, 234E, 234F, 234I, Tables 234-1, 234-2, 234-3)

Line conditions under which the NESC vertical clearances shall be met (Calculations are based on Maximum Operating Voltage.):

- 32°F, no wind, with radial thickness of ice, if any, specified in Rule 250B of the NESC for the loading district concerned.
- Maximum conductor temperature for which the line is designed to operate, with no horizontal displacement

Nominal Voltage, Phase to Phase (kV_{LL})		**34.5 & 46**	**69**	**115**	**138**	**161**	**230 (E)**
Max. Operating Voltage, Phase to Phase	(kV_{LL})	----	72.5	120.8	144.9	169.1	241.5
Max. Operating Voltage, Phase to Ground	(kV_{LG})	----	41.8	69.7	83.7	97.6	139.4
	NESC Basic Clear.(Note D)	Clearances in feet					
1.0 From a lighting support, traffic signal support, or supporting structure of a second line	5.5	7.5	7.5	8.2	8.6	9.1	10.8
2.0 From buildings not accessible to pedestrians	12.5	14.7	15.2	16.1	16.6	17.0	18.4
3.0 From buildings – accessible to pedestrians and vehicles but not truck traffic	13.5	15.7	16.2	17.1	17.6	18.0	19.4
4.0 From buildings – over roofs accessible to truck traffic	18.5	20.7	21.2	22.1	22.6	23.0	24.4
5.0 From signs, chimneys, billboards, radio & TV antennas, tanks & other installations **not accessible to personnel**.	8.0	10.2	10.7	11.6	12.1	12.5	13.9
6.0 From bridges – not attached (Note C)	12.5	14.7	15.2	16.1	16.6	17.0	18.4
7.0 From grain bins probe ports	18.0	20.2	20.7	21.6	22.1	22.5	23.9
8.0 Clearance in any direction from swimming pool edge and diving platform base **(Clearance A, Figure 4-4)**	25.0	27.2	27.7	28.6	29.1	29.5	30.9
Clearance in any direction from diving structures **(Clearance B, Figure 4-4)**	17.0	19.2	19.7	20.6	21.1	21.5	22.9
ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE							
Additional feet of clearance per 1000 feet of altitude above 3300 feet		.00	.02	.05	.07	.08	.12

Notes:

(A) An additional 2.0 feet of clearance is added to NESC clearance to obtain the recommended design clearances. Greater values should be used where the survey method used to develop the ground profile is subject to greater unknowns.
(B) Other supporting structures include lighting supports, traffic signal supports, or a supporting structure of another line.
(C) If the line crosses a roadway, then Table 4-1, line 2.0 clearances are required.
(D) The NESC basic clearance is defined as the reference height plus the electrical component for open supply conductors up to 22 kV_{LG} except row '1.0' where voltage referenc is 50 kV_{LG}
(E) For 230 kV, clearances may be required to be higher if switching surges are greater than 2.0 per unit. See NESC Tables 234-4 and 234-5.

4.4.5 Examples of Clearance Calculations: The following examples demonstrate the derivation of the vertical clearances shown in Tables 4-1 and 4-2.

To determine the vertical clearance of a 161 kV line crossing a road (category 2.0 of Table 4-1), the clearance is based on NESC Table 232-1 and NESC Rule 232.

NESC Vertical Clearance = NESC Basic Clearance(Table 232-1) + .4(kV_{L-G} – 22)/12
= 18.5 feet + .4(97.6-22)/12 feet
= 18.5 feet + 2.52 feet
NESC Vertical Clearance = 21.02 feet

Recommended Clearance = NESC Vertical Clearance + Agency Adder
= 21.02 feet + 2.5 feet
= 23.52 feet (23.5 feet in Table 4-1)

To determine the vertical clearance of a 230 kV line over a building roof not accessible to pedestrians (category 2.0 of Table 4-2), the clearance is based on NESC Table 234-1 and NESC Rule 234.

NESC Vertical Clearance = NESC Basic Clearance(Table 234-1) + .4(kV_{L-G} – 22)/12
= 12.5 feet + .4(139-22)/12 feet
= 12.5 feet + 3.9 feet
NESC Vertical Clearance = 16.4 feet

Recommended Clearance = NESC Vertical Clearance + Agency Adder
= 16.4 feet + 2.0 feet
= 18.4 feet (18.4 feet in Table 4-2)

4.5 Design Vertical Clearance Between Conductors Where One Line Crosses Over or Under Another: Recommended design vertical clearances between conductors when one line crosses another are provided in Table 4-3. The clearance values in Table 4-3 are for transmission lines which are known to have ground fault relaying. The clearances should be maintained at the point where the conductors cross, regardless of where the point of crossing is located on the span.

4.5.1 Conditions Under Which Clearances Apply: The clearances apply for an upper conductor at final sag for the conditions ‘a’ through ‘c’. The condition that produces the greatest sag for the line is the one that applies.

a. A conductor temperature of 32°F, no wind, with a radial thickness of ice for the loading district concerned.

b. A conductor temperature of 167°F. A lower temperature may be considered where justified by a qualified engineering study. Under no circumstances should a design temperature be less than 120°F.

c. Maximum conductor temperature, no wind. See paragraph 4.3.1. The same maximum temperature used for vertical clearance to ground should be used.

At a minimum the NESC requires that (1) the upper and lower conductors are simultaneously subjected to the same ambient air temperature and wind loading conditions **and** (2) each is subjected individually to the full range of its icing conditions and applicable design electrical loading.

4.5.2 Altitude Greater than 3300 Feet: If the altitude of the crossing point of the two lines is greater than 3300 feet, additional clearance as indicated in Table 4-3 is added to the base clearance given.

4.5.3 Differences in Sag Conditions Between Lower and Upper Conductors: The reason for the differences in sag conditions between the upper and lower conductor at which the clearances apply is to cover situations where the lower conductor has lost its ice while the upper conductor has not, or where the upper conductor is loaded to its thermal limit while the lower conductor is only lightly loaded.

4.5.4 Examples of Clearance Calculations: The following example demonstrates the derivation of the vertical clearance of a category in Tables 4-3 of this bulletin.

To determine the vertical clearance of a 161 kV line crossing a distribution conductor (item 3 of Table 4-3), the clearance is based on NESC Table 233-1 and NESC Rule 233.

NESC Vertical Clearance= NESC Basic Clearance(Table 233-1) + .4(kV_{L-G} – 22)/12
= 2.0 feet + .4(97.6-22)/12 feet
= 2.0 feet + 2.5 feet
NESC Vertical Clearance = 4.5 feet

Recommended Clearance = NESC Vertical Clearance + Agency Adder
= 4.5 feet + 1.5 feet
= 6.0 feet (6.0 feet in Table 4-3)

4.6 Design Vertical Clearance Between Conductors of Different Lines at Noncrossing Situations: If the horizontal separation between conductors as set forth in Chapter 5 cannot be achieved, then the clearance requirements in section 4.5 should be attained.

4.7 Example of Line-to-Ground Clearance: A portion of a 161 kV line is to be built over a field of oats that is at an elevation of 7200 feet. Determine the design line-to-ground clearance.

4.7.1 Solution of the Additional Clearance for Altitude: Because the altitude of the 161 kV line is greater than 3300 feet, the basic clearance is to be increased by the amount indicated in Table 4-1. The calculation follows:

(7200-3300)(.08)/1000 = 0.32 feet

4.7.2 Total Clearance: Assuming the line meets the assumptions given in section 4.2 and Table 4-1, the recommended design clearance over cultivated fields for a 161 kV line is 23.5 feet. Therefore, the recommended clearance, taking altitude into account, is 23.8 feet.

0.32 feet + 23.5 feet = 23.8 feet

An additional one foot of clearance should be added for survey, construction and design tolerance.

4.8 Example of Conductor Crossing Clearances: A 230 kV line crosses over a 115 kV line in two locations. At one location the 115 kV line has an overhead ground wire which, at the point of crossing, is 10 feet above its phase conductors. At the other location the lower voltage line does not have an overhead ground wire. Determine the required clearance between the 230 kV conductors and the 115 kV conductors at both crossing locations. Assume that the altitude of the line is below 3300 feet. Also assume that the sag of the overhead ground wire is the same as or less than the sag of the 115 kV phase conductors. The 230 kV line has ground fault relaying.

Solution: The first step in the solution is to determine if the line being crossed over has automatic ground fault relaying. We are able to determine that the lower line has automatic ground fault relaying.

From Table 4-3, (item 4), the required clearance from a 230 kV conductor to a 115 kV conductor is 9.0 feet. From Table 4-3, (item 2), the required clearance from the 230 kV conductor to the overhead ground wire is 7.4 feet; adding 10 feet for the distance between the overhead ground wire (OHGW) and the 115 kV phase conductors, the total required clearance is 17.4 feet.

When the lower circuit has an overhead ground wire, clearance requirements to the overhead ground wire govern and the required clearance between the upper and lower phase conductor is 17.4 feet.

Where there is no overhead ground wire for the 115 kV circuit, the required clearance between the phase conductors is 9.0 feet.

It is important to note that the above clearances are to be maintained where the upper conductor is at its maximum sag condition, as defined in section 4.5.1b or 4.5.1c above, and the lower conductor is at 60°F initial sag.

4.9 Vertical Clearances to Vegetation: The best practice is usually to remove all substantive vegetation (such as trees and vines) under and adjacent to the line. In certain areas, such as canyons, river crossings, or endangered species habitat, vegetation can be spanned. For vertical clearances (intended to meet NERC FAC 003), refer to radial clearances discussed in Section 5.2.2 of this bulletin.

TABLE 4-3
RECOMMENDED DESIGN VERTICAL CLEARANCES IN FEET BETWEEN CONDUCTORS WHERE THE CONDUCTORS OF ONE LINE CROSS OVER THE CONDUCTORS OF ANOTHER AND WHERE THE UPPER AND LOWER CONDUCTORS HAVE GROUND FAULT RELAYING

Voltage between circuits = Voltage line to ground Top Circuit + Voltage line to ground Bottom Circuit (Calculations are based on the maximum operating voltage.)

The NESC requires that clearances not be less than that required by application of a clearance envelope developed under NESC Rules 233A1 & 233A2. Structure deflection shall also be taken into account. Agency recommended values in this table are to be adders applied for the movement of the conductor and deflection of structures, if any.

			UPPER LEVEL CONDUCTOR (Note F)					
Nominal Voltage, Phase to Phase kV $_{L-L}$			**34.5 & 46**	**69**	**115**	**138**	**161**	**230**
Max. Operating Voltage, Phase to Phase		(kV_{LL})	----	72.5	120.8	144.9	169.1	241.5
Max. Operating Voltage, Phase to Ground		(kV_{LG})	----	41.8	69.7	83.7	97.6	139.4
	NESC Basic Clear. (Note H)	(kV_{LG})	Clearances in feet					
LOWER LEVEL CONDUCTOR								
1. Communication	5.0		6.7	7.2	8.1	8.6	9.0	10.4
2. OHGW (Note G)	2.0		3.7	4.2	5.1	5.6	6.0	7.4
3. Distribution conductors	2.0		3.7	4.2	5.1	5.6	6.0	7.4
4. Transmission conductors of lines that have ground fault relaying. Nominal line – to – line voltage in kV. (Note F)								
230 kV	2.0	139.4						11.3
161 kV	2.0	97.6					8.5	9.9
138 kV	2.0	83.7				7.6	8.1	9.5
115 kV	2.0	69.7			6.7	7.1	7.6	9.0
69 kV	2.0	41.8		4.8	5.6	6.2	6.7	8.1
46 kV and below	2.0	26.4	3.8	4.3	5.2	5.7	6.2	7.6

Notes:

(A) The conductors on other supports are assumed to be from different circuits

(B) **This table applies to lines with ground fault relaying.**

(C) The NESC requires that the clearance shall be not less than that required by application of a clearance envelope developed under NESC Rule 233A2 to the positions on or within conductor movement envelopes developed under Rule 233A1 at which the two wires, conductors or cables would be closest together. For purposes of this determination, the relevant positions of the wires, conductors, or cables on or within their respective conductor movement envelopes are those which can occur when (1) both are simultaneously subjected to the same ambient air temperature and wind loading conditions and (2) each is subjected individually to the full range of its icing conditions and applicable design electrical loading.

TABLE 4-3 (continued)
RECOMMENDED DESIGN VERTICAL CLEARANCES IN FEET
BETWEEN CONDUCTORS WHERE THE CONDUCTORS OF ONE LINE
CROSS OVER THE CONDUCTORS OF ANOTHER AND WHERE THE UPPER AND
LOWER CONDUCTORS HAVE GROUND FAULT RELAYING

(D) An additional 1.5 feet of clearance is added to NESC clearance to obtain the recommended design clearances. Greater values should be used where the survey method used to develop the ground profile is subject to greater unknowns.

(E) ***ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE***

Total altitude correction factor	=	Correction for upper conductors	+	Correction for lower conductors

For upper conductors use correction factor from Table 4-1 of this bulletin.
For lower conductors:
Categories 1, 2, 3 above use no correction factors
Category 4 uses correction factors from Table 4-1 of this bulletin

(F) **The higher voltage line should cross over the lower voltage line**

(G) If the line on the lower level has overhead ground wire(s), this clearance will usually be the limiting factor at crossings.

(H) The NESC basic clearance is defined as the reference height plus the electrical component for open supply conductors up to 22 kV_{L-G}.

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5. HORIZONTAL CLEARANCES FROM LINE CONDUCTORS TO OBJECTS AND RIGHT-OF-WAY WIDTH

5.1 General: The preliminary comments and assumptions in Chapter 4 of this bulletin also apply to this chapter.

5.2 Minimum Horizontal Clearance of Conductor to Objects: Recommended design horizontal clearances of conductors to various objects are provided in Table 5-1 and minimum radial operating clearances of conductors to vegetation in Table 5-2. The clearances apply only for lines that are capable of automatically clearing line-to-ground faults.

Clearance values provided in Table 5-1are recommended design values. In order to provide an additional margin of safety, the recommended design values exceed the minimum clearances in the 2007 NESC. Clearance values provided in Table 5-2 are minimum operating clearances to be used by the designer to determine appropriate design clearances for vegetation maintenance management.

5.2.1 Conditions Under Which Horizontal Clearances to Other Supporting Structures, Buildings and Other Installations Apply:

Conductors at Rest (No Wind Displacement): When conductors are at rest the clearances apply for the following conditions: (a) 167°F but not less than 120°F, final sag, (b) the maximum operating temperature the line is designed to operate, final sag, (c) 32°F, final sag with radial thickness of ice for the loading district (0 in., ¼ in., or ½ in.).

Conductors Displaced by 6 psf Wind: The clearances apply when the conductor is displaced by 6 lbs. per sq. ft. at final sag at 60°F. See Figure 5-1.

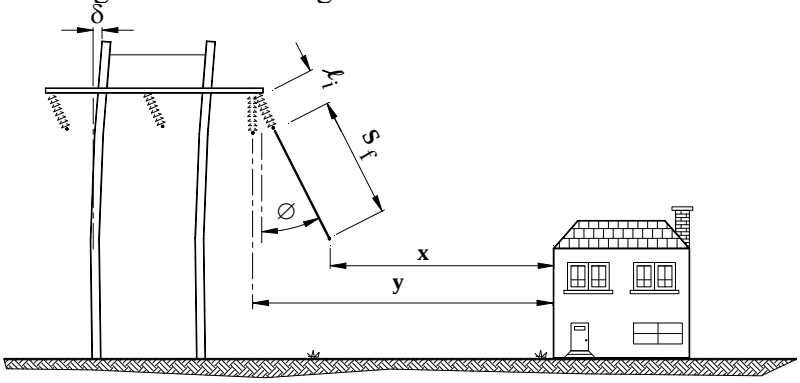

FIGURE 5-1: HORIZONTAL CLEARANCE REQUIREMENT TO BUILDINGS

where:

ϕ	=	conductor swing out angle in degrees under 6 psf. of wind
S_f	=	conductor final sag at 60°F with 6 psf. of wind
x	=	horizontal clearance required per Tables 5-1 for conductors displaced by 6 psf wind (include altitude correction if necessary)
ℓ_i	=	insulator string length ($\ell_i = 0$ for post insulators or restrained suspension insulators).
y	=	total horizontal distance from insulator suspension point (conductor attachment point for post insulators) to structure with conductors at rest
δ	=	structure deflection with a 6 psf. Wind

TABLE 5-1
RECOMMENDED DESIGN HORIZONTAL CLEARANCES (in feet) FROM CONDUCTORS AT REST AND DISPLACED BY 6 PSF WIND TO OTHER SUPPORTING STRUCTURES, BUILDINGS AND OTHER INSTALLATIONS
(NESC Rules 234B, 234C, 234D, 234E, 234F, 234I, Tables 234-1, 234-2, 234-3)

Conditions under which clearances apply:

No wind: When the conductor is at rest the clearances apply at the following conditions: (a) 120°F, final sag, (b) the maximum operating temperature the line is designed to operate, final sag, (c) 32°F, final sag with radial thickness of ice for the loading district (1/4 in. for Medium or 1/2 in. Heavy).

Displaced by Wind: Horizontal clearances are to be applied with the conductor displaced from rest by a 6 psf wind at final sag at 60°F. The displacement of the conductor is to include deflection of suspension insulators and deflection of flexible structures.

The clearances shown are for the displaced conductors and do not provide for the horizontal distance required to account for blowout of the conductor and the insulator string. This distance is to be added to the required clearance. See Equation 5-1.

Clearances are based on the Maximum Operating Voltage

Nominal voltage, Phase to Phase, kV_{L-L}		**34.5 & 46**	**69**	**115**	**138**	**161**	**230**
Max. Operating Voltage, Phase to Phase, kV_{L-L}		----	72.5	120.8	144.9	169.1	241.5
Max. Operating Voltage, Phase to Ground, kV_{L-G}		----	41.8	69.7	83.7	97.6	139.4
Horizontal Clearances - (Notes 1,2,3)	NESC Basic Clear	Clearances in feet					
1.0 From a lighting support, traffic signal support or supporting structure of another line							
At rest **(NESC Rule 234B1a)**	5.0	6.5	6.5	7.2	7.6	8.1	9.5
Displaced by wind **(NESC Rule 234B1b)**	4.5	6.2	6.7	7.6	8.1	8.5	9.9
2.0 From buildings, walls, projections, guarded windows, windows not designed to open, balconies, and areas accessible to pedestrians							
At rest **(NESC Rule 234C1a)**	7.5	9.2	9.7	10.6	11.1	11.5	12.9
Displaced by wind **(NESC Rule 234C1b)**	4.5	6.2	6.7	7.6	8.1	8.5	9.9
3.0 From signs, chimneys, billboards, radio, & TV antennas, tanks & other installations not classified as buildings							
At rest **(NESC Rule 234C1a)**	7.5	9.2	9.7	10.6	11.1	11.5	12.9
Displaced by wind **(NESC Rule 234C1b)**	4.5	6.2	6.7	7.6	8.1	8.5	9.9
4.0 From portions of bridges which are readily accessible and supporting structures are not attached							
At rest **(NESC Rule 234D1a)**	7.5	9.2	9.7	10.6	11.1	11.5	12.9
Displaced by wind **(NESC Rule 234D1b)**	4.5	6.2	6.7	7.6	8.1	8.5	9.9
5.0 From portions of bridges which are ordinarily inaccessible and supporting structures are not attached							
At rest **(NESC Rule 234D1a)**	6.5	8.2	8.7	9.6	10.1	10.5	11.9
Displaced by wind **(NESC Rule 234D1b)**	4.5	6.2	6.7	7.6	8.1	8.5	9.9

TABLE 5-1 (continued)
RECOMMENDED DESIGN HORIZONTAL CLEARANCES (in feet) FROM CONDUCTORS AT REST AND DISPLACED BY 6 PSF WIND TO OTHER SUPPORTING STRUCTURES, BUILDINGS AND OTHER INSTALLATIONS
(NESC Rules 234B, 234C, 234D, 234E, 234F, 234I, Tables 234-1, 234-2, 234-3)

Conditions under which clearances apply:

No wind: When the conductor is at rest the clearances apply at the following conditions: (a) 120°F, final sag, (b) the maximum operating temperature the line is designed to operate, final sag, (c) 32°F, final sag with radial thickness of ice for the loading district (1/4 in. for Medium or 1/2 in. Heavy).

Displaced by Wind: Horizontal clearances are to be applied with the conductor displaced from rest by a 6 psf wind at final sag at 60°Funder extreme wind conditions (such as the 50 or 100-year mean wind) at final sag at 60°F. The displacement of the conductor is to include deflection of suspension insulators and deflection of flexible structures.

The clearances shown are for the displaced conductors and do not provide for the horizontal distance required to account for blowout of the conductor and the insulator string. This distance is to be added to the required clearance. See Equation 5-1.

Clearances are based on the Maximum Operating Voltage

Nominal voltage, Phase to Phase, kV_{L-L}		**34.5 & 46**	**69**	**115**	**138**	**161**	**230**
Max. Operating Voltage, Phase to Phase, kV_{L-L}		----	72.5	120.8	144.9	169.1	241.5
Max. Operating Voltage, Phase to Ground, kV_{L-G}		----	41.8	69.7	83.7	97.6	139.4
Horizontal Clearances - (Notes 1,2,3)	NESC Basic Clear	Clearances in feet					
6.0 Swimming pools – see section 4.4.3 of Chapter 4 and item 9 of Table 4–2. (NESC Rule 234E)							
Clearance in any direction from swimming pool edge (Clearance A, Figure 4-2 of this bulletin)	25.0	27.2	27.7	28.6	29.1	29.5	30.9
Clearance in any direction from diving structures (Clearance B, Figure 4-2 of this bulletin)	17.0	19.2	19.7	20.6	21.1	21.5	22.9
7.0 From grain bins loaded with permanently attached conveyor							
At rest (NESC Rule 234F1b)	15.0	17.2	17.7	18.6	19.1	19.5	20.9
Displaced by wind (NESC Rule 234C1b)	4.5	6.7	7.2	8.1	8.6	9.0	10.4
8.0 From grain bins loaded with a portable conveyor. Height 'V' of highest filling or probing port on bin must be added to clearance shown. Clearances for 'at rest' and not displaced by the wind. See NESC Figure 234-4 for other requirements.							
Horizontal clearance envelope (includes area of sloped clearance per NESC Figure 234-4b)		(24+V) + 1.5V (Note 3)					
9.0 From rail cars (Applies only to lines parallel to tracks) See Figure 234-5 and section 234I (Eye) of the NESC							
Clearance measured to the nearest rail		14.1	14.1	15.1	15.6	16.0	17.5
ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE							
Additional feet of clearance per 1000 feet of altitude above 3300 feet		.02	.02	.05	.07	.08	.12

Notes:

1. Clearances for categories 1-5 in the table are approximately 1.5 feet greater than NESC clearances.
2. Clearances for categories 6 to 9 in the table are approximately 2.0 feet greater than NESC clearances.
3. "V" is the height of the highest filling or probing port on a grain bin. Clearance is for the highest voltage of 230 kV.

5.2.2 Considerations in Establishing Radial and Horizontal Clearances to Vegetation:

The designer should identify and document clearances between vegetation and any overhead, ungrounded supply conductors, taking into consideration transmission line voltage, the effects of ambient temperature on conductor sag under maximum design loading, and the effects of wind velocities on conductor sway. Specifically, the designer should establish clearances to be achieved at the time of vegetation management work and should also establish and maintain a set of clearances to prevent flashover between vegetation and overhead ungrounded supply conductors. As a mimimum, these clearances should apply to all transmission lines operated at 200 kV phase-to-phase and above and to any lower voltage lines designated as critical (refer to NERC FAC 003).

The designer should determine and document appropriate clearance distances to be achieved at the time of transmission vegetation management work based upon local conditions and the expected time frame in which the Transmission Owner plans to return for future vegetation management work. Local conditions may include, but are not limited to: operating voltage, appropriate vegetation management techniques, fire risk, reasonably anticipated tree and conductor movement, species types and growth rates, species failure characteristics, local climate and rainfall patterns, line terrain and elevation, location of the vegetation within the span, and worker approach distance requirements.

The designer should determine and document specific radial clearances to be maintained between vegetation and conductors under all rated electrical operating conditions. These minimum clearance distances are necessary to prevent flashover between vegetation and conductors and will vary due to such factors as altitude and operating voltage. These specific minimum clearance distances should be no less than those set forth in the Institute of Electrical and Electronics Engineers (IEEE) Standard 516-2003 (Guide for Maintenance Methods on Energized Power Lines) and as specified in its Section 4.2.2.3, Minimum Air Insulation Distances without Tools in the Air Gap. Where transmission system transient overvoltage factors are not known, clearances shall be derived from Table 5, IEEE 516-2003, phase-to-ground distances, with appropriate altitude correction factors applied.Where transmission system transient overvoltage factors are known, clearances shall be derived from Table 7, IEEE 516-2003, phase-to-phase voltages, with appropriate altitude correction factors applied. Table 5-2 contains radial clearances determined from Table 5, IEEE 516-2003, where transmission system transient overvoltage factors are not known.

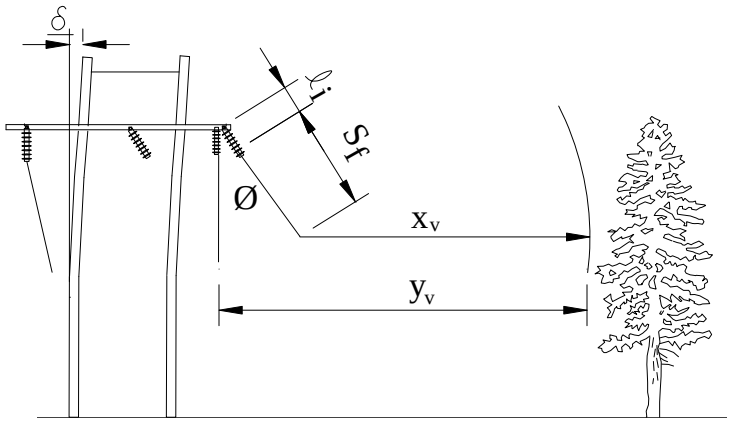

FIGURE 5-2: RADIAL CLEARANCE REQUIREMENT TO VEGETATION

where:

ϕ = conductor swing out angle in degrees under all rated operating conditions
S_f = conductor final sag at all rated operating conditions
x_v = radial clearance (include altitude correction if necessary)
ℓ_i = insulator string length ($\ell_i = 0$ for post insulators or restrained suspension insulators).
y_v = horizontal clearance at the time of vegetation management work
δ = structure deflection at all rated operating conditions

TABLE 5-2
RADIAL OPERATING CLEARANCES (in feet) FROM IEEE 516 FOR USE IN DETERMINING CLEARANCES TO VEGETATION FROM CONDUCTORS
(NERC Standard FAC-003.1 Transmission Vegetation Management Program, IEEE 516, Guideline For Maintenance Methods Of Energized Power Lines)

Conditions under which clearances apply:

Displaced by Wind: Radial operating clearances are to be applied at all rated operating conditions.The designer should determine applicable conductor temperature and wind conditions for all rated operating conditions. The displacement of the conductor is to include deflection of suspension insulators and deflection of flexible structures.

The operating clearances shown are for the displaced conductors and do not provide for the horizontal distance required to account for blowout of the conductor and the insulator string. This distance is to be added to the required clearance. See Equation 5-1.

Clearances are based on the Maximum Operating Voltage.

Nominal voltage, Phase to Phase, kV_{L-L}	**34.5 & 46[1]**	**69[1]**	**115[1]**	**138[1]**	**161[1]**	**230[1,2]**
Max. Operating Voltage, Phase to Phase, kV_{L-L}	----	72.5	120.8	144.9	169.1	241.5
Max. Operating Voltage, Phase to Ground, kV_{L-G}	----	41.8	69.7	83.7	97.6	139.4
Radial Table 5 IEEE Standard 516 Operating Clearances	Clearances in feet					
Operating clearance at all rated operating conditions	1.8	1.8	1.9	2.3	2.5	2.7
Design adder for survey and installation tolerance	1.5 feet for all voltages					
Design adder for vegetation	Determined by designer (see Note 3 below)					
ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE						
Additional feet of clearance per 1000 feet of altitude above 3300 feet	.02	.02	.05	.07	.08	.12

Notes:

1. These clearances apply to all transmission lines operated at 200 kV phase-to-phase and above and to any lower voltage lines designated as critical (refer to NERC FAC 003).
2. The 230 kV clearance is based on 3.0 Per Unit switching surge.
3. The design adder for vegetation, applied to conductors displaced by wind, should account for reasonably anticipated tree movement, species types and growth rates, species failure characteristics, and local climate and rainfall patterns. The design adder for vegetation, applied to conductors at rest, should account for worker approach distances in addition to the aforementioned factors.

5.2.3 Clearances to Grain Bins: The NESC has defined clearances from grain bins based on grain bins that are loaded by permanent or by portable augers, conveyers, or elevator systems.

In NESC Figure 234-4(a), the horizontal clearance envelope for permanent loading equipment is graphically displayed and shown Figure 5-2.

P = probe clearance, item 7, Table 4-2
H = horizontal clearance, item 7, Table 5-1
T = transition clearance
V_1 = vertical clearance, item 2&3, Table 4-2
V_2 = vertical clearance, Table 4-1

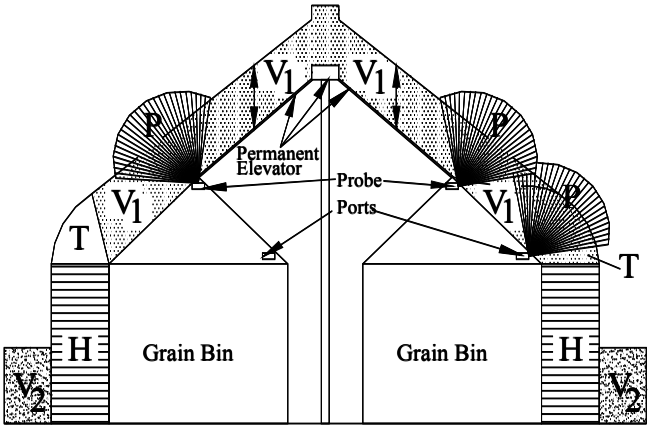

FIGURE 5-3: CLEARANCE TO GRAIN BINS
NESC FIGURE 234-4a
From IEEE/ANSI C2-2007, National Electrical Safety Code, Copyright 2006. All rights reserved.

Because the vertical distance from the probe in Table 4-2, item 7.0, is greater than the horizontal distance, (see Table 5-1, item 7.0), the user may want to simplify design and use this distance as the horizontal clearance distance as shown below:

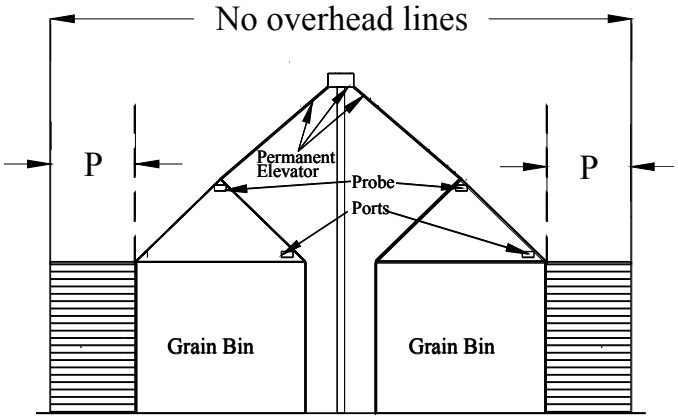

FIGURE 5-4: HORIZONTAL CLEARANCE TO GRAIN BINS, CONDUCTORS AT REST
P = clearance from item 7, Table 4-2

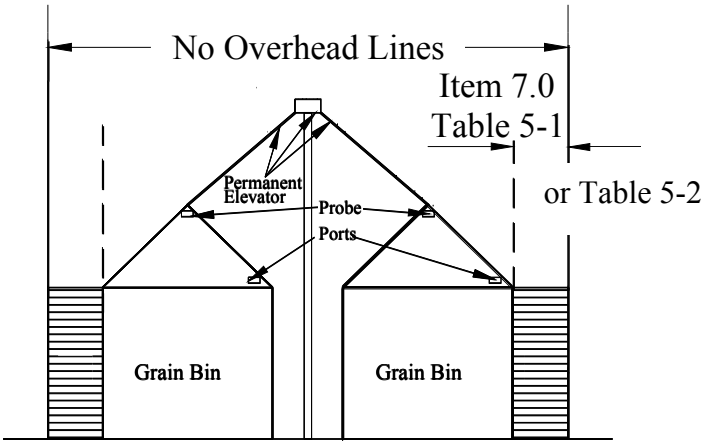

FIGURE 5-5: HORIZONTAL CLEARANCE TO GRAIN BINS, CONDUCTORS DISPLACED BY 6 PSF WIND

The clearance envelope for portable loading equipment from NESC Figure 234(b), is shown in Figure 5-6.

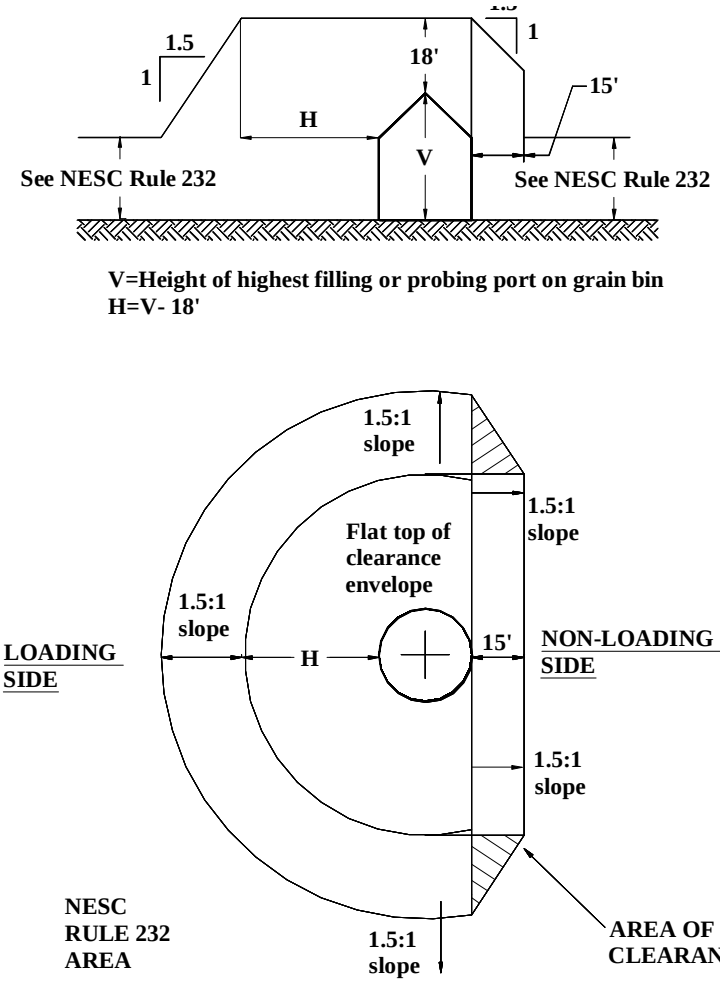

FIGURE 5-6: NESC CLEARANCE TO GRAIN BINS WITH PORTABLE LOADING EQUIPMENT

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In order to simplify the clearance envelope, the horizontal clearances in category 8 of Table 5-1 is shown as 'H' in the drawing below:

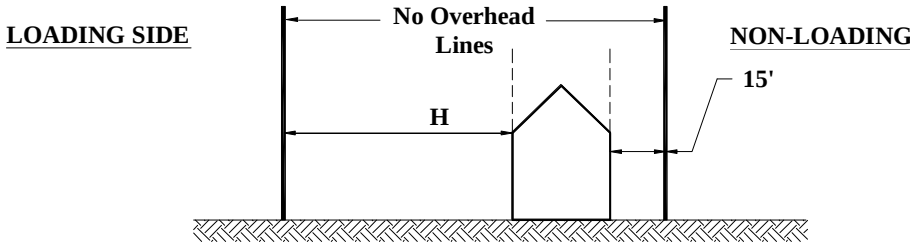


FIGURE 5-7: SIMPLIFIED RECOMMENDATIONS FOR CLEARANCES TO GRAIN BINS WITH PORTABLE LOADING EQUIPMENT

5.2.4 Altitude Greater Than 3300 Feet: If the altitude of the transmission line or portion thereof is greater than 3300 feet, an additional clearance as indicated in Table 5-1 and 5-2 has to be added to the base clearance given.

5.2.5 Total Horizontal Clearance to Point of Insulator Suspension to Object: As can be seen from Figure 5-1, the total horizontal clearance (y) is:

$$y = (\ell_i + S_f)\sin\phi + x + \delta \qquad \text{Eq. 5-1}$$

Symbols are defined in Section 5.2.1 and figure 5-1. The factor "δ" indicates that structure deflection should be taken into account.

For the sake of simplicity when determining **horizontal** clearances, the insulator string should be assumed to have the same swing angle as the conductor. This assumption should be made only in this chapter as its use in calculations elsewhere may not be appropriate.

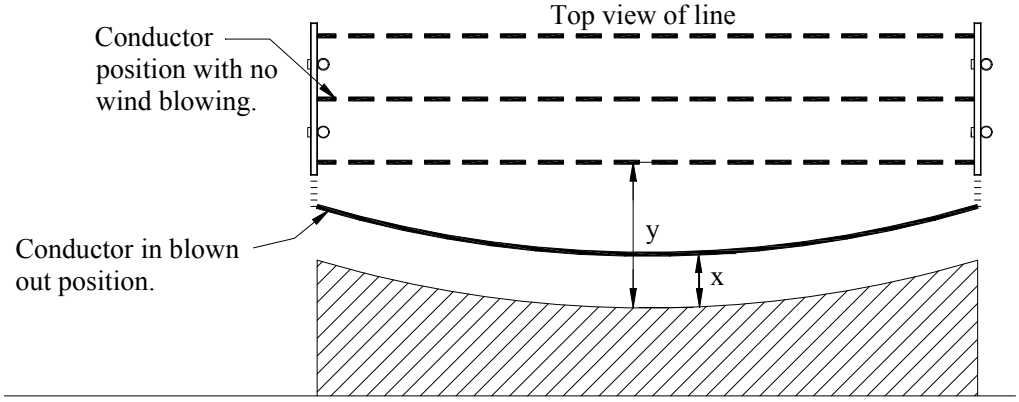
The conductor swing angle (ϕ) under wind can be determined from the formula.

$$\phi = \tan^{-1}\left(\frac{(d_c)(F)}{12\ w_c}\right) \qquad \text{Eq. 5-2}$$

where:

d_C = conductor diameter in inches
w_C = weight of conductor in lbs./ft.
F = wind force;

The total horizontal distance (y) at a particular point in the span depends upon the conductor sag at that point. The value of (y) for a structure adjacent to the maximum sag point will be greater than the value of (y) for a structure placed elsewhere along the span. See Figure 5-7.



x = clearance from wind-displaced conductor, y= total horizontal clearance from conductor at rest

FIGURE 5-8: A TOP VIEW OF A LINE SHOWING TOTAL HORIZONTAL CLEARANCE REQUIREMENTS

5.2.6 Examples of Horizontal Clearance Calculations: The following examples demonstrate the derivation of the horizontal clearance in Table 5-1 of this bulletin.

To determine the horizontal clearance of a 115 kV line to a building (category 2.0 of Table 5-1), the clearance is based on NESC Table 234-1 and NESC Rule 234.

At rest:

NESC Horizontal Clear. = NESC Basic Clearance(Table 234-1) + .4(kV_{L-G} – 22)/12
= 7.5 feet + .4(69.7-22)/12 feet
= 7.5 feet + 1.59 feet
NESC Horizontal Clear. = 9.09 feet

Recommended Clearance = NESC Horizontal Clearance + Adder
= 9.09 feet + 1.5 feet
y = 10.59 feet (10.60 feet in Table 5-1)

Conductors displaced by 6 psf wind:

NESC Horizontal Clear. = NESC Basic Clearance (Table 234-1) + .4(kV_{L-G} – 22)/12
= 4.5 feet + .4(69.7-22)/12 feet
= 4.5 feet + 1.59 feet
NESC Horizontal Clear. = 6.09 feet

Recommended Clearance = NESC Horizontal Clearance + Adder
= 6.09 feet + 1.5 feet
x = 7.59 feet (7.6 feet in Table 5-1)

5.3 Right-of-Way (ROW) Width: For transmission lines, a right-of-way provides an environment allows the line to be operated and maintained safely and reliably. Determination of the right-of-way width is a task that requires the consideration of a variety of judgmental, technical, and economic factors.

Typical right-of-way widths (predominantly H-frames) that have been used by agency borrowers in the past are shown in Table 5-2. In many cases a range of widths is provided. The actual width used will depend upon the particulars of the line design.

TABLE 5-3
TYPICAL RIGHT-OF-WAY WIDTHS

	Nominal Line-to-Line Voltage in kV				
	69	115	138	161	230
ROW Width, ft.	75-100	100	100-150	100-150	125-200

5.4 Calculation of Right-of-Way Width for a Single Line of Structures on a Right-of-Way: Right-of-way widths can be calculated using the method described below. The calculated values for right-of-way widths are directly related to the particular parameters of the line design. This method provides sufficient width to meet clearance requirements to buildings of undetermined height or vegetation located directly on the edge of the right-of-way. See Figures 5-8 and 5-9.

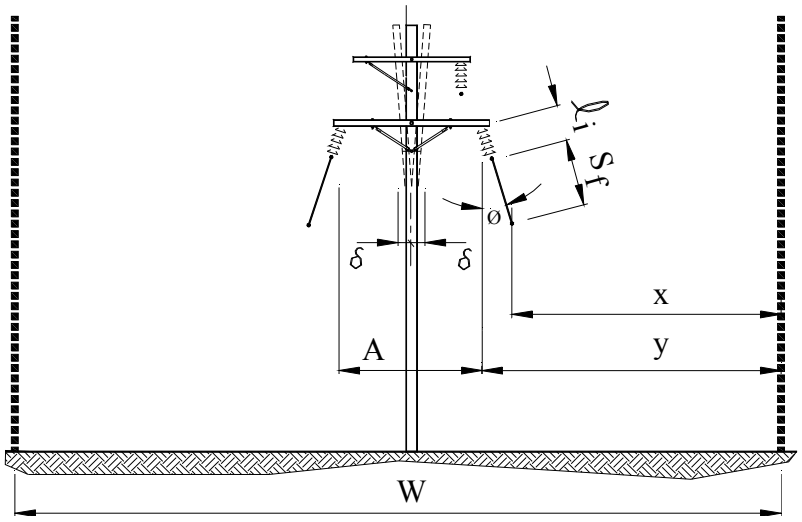


FIGURE 5-9: ROW WIDTH FOR SINGLE LINE OF STRUCTURES

$$W = A + 2(\ell_i + S_f)\sin\phi + 2\delta + 2x \qquad \text{Eq. 5-3}$$

where:

W = total right-of-way width required
A = separation between points of suspension of insulator strings for outer two phases
x = clearance required per Table 5-1 and appropriate clearance derived from Table 5-2 of this bulletin (include altitude correction if necessary)
y = clearance required per Section 5.2.1 and Table 5-1 and appropriate clearance derived from Section 5.2.2. and Table 5-2 of this bulletin (include altitude correction if necessary)

Other symbols are as previously defined. In some instances, clearance "x" may control. In other instances, clearance "y" may control.

There are two ways of choosing the length (and thus the sag) on which the right-of-way width is based. One is to use a width based on the maximum span length in the line. The other way is to base the width on a relatively long span, (the ruling span, for instance), but not the longest span. For those spans that exceed this base span, additional width is added as appropriate.

5.5 Right-of-Way Width for a Line Directly Next to a Road: The right-of-way width for a line next to a road can be calculated based on the two previous sections with one exception. No ROW is needed on the road side of the line as long as the appropriate clearances to existing or possible future structures on the road side of the line are met.

If a line is to be placed next to a roadway, consideration should be given to the possibility that the road may be widened. If the line is on the road right-of-way, the borrower would generally be expected to pay for moving the line. If the right-of-way is on private land, the highway

department should pay. Considerations involved in placing a line on a road right-of-way should also include evaluation of local ordinances and requirements.

5.6 Right-of-Way Width for Two or More Lines of Structures on a Single Right-of-Way: To determine the right-of-way width when the right ROW contains two parallel lines, start by calculating the distance from the outside phases of the lines to the ROW edge (see Section 5.4). The distance between the two lines is governed by the two criteria provided in section 5.6.1. If one of the lines involved is an extra high voltage (EHV) line (345 kV and above), the NESC should be referred to for additional applicable clearance rules not covered in this bulletin.

5.6.1 Separation Between Lines as Dictated by Minimum Clearance Between Conductors Carried on Different Supports: The horizontal clearance between a phase conductor of one line to a phase conductor of another line shall meet the larger of C_1, or C_2 below, under the following conditions: (a) both phase conductors displaced by a 6 psf wind at 60°F, final sag; (b) if insulators are free to swing, one should be assumed to be displaced by a 6 lbs/sq. ft. wind while the other should be assumed to be unaffected by the wind (see Figure 5-10). The assumed wind direction should be that which results in the greatest separation requirement. It should be noted that in the Equations 5-5, and 5-6, the 'δ_1-δ_2' term, (the differential structure deflection between the two lines of structures involved), is to be taken into account. An additional 1.5 feet have been added to the NESC clearance to obtain design clearances 'C_1'and 'C_2'. Note Equation 5-6 has been revised from previous versions due to the voltage adder change in the 2007 NESC edition.

$$C_1 = 6.5 + (\delta_1 - \delta_2) \text{ (NESC Rule 233B1)} \qquad \text{Eq. 5-5}$$

$$C_2 = 6.5 + \frac{.4}{12}\left[(kV_{LG1} + kV_{LG2}) - 22\right] + (\delta_1 - \delta_2) \text{ (NESC Rule 233B1)} \qquad \text{Eq. 5-6}$$

where:

C_1, C_2 = clearance requirements between conductors on different lines in feet (largest value governs)
kV_{LG1} = maximum line-to-ground voltage in kV of line 1
kV_{LG2} = maximum line-to-ground voltage in kV of line 2
δ_1 = deflection of the upwind structure in feet
δ_2 = deflection of the downwind structure in feet

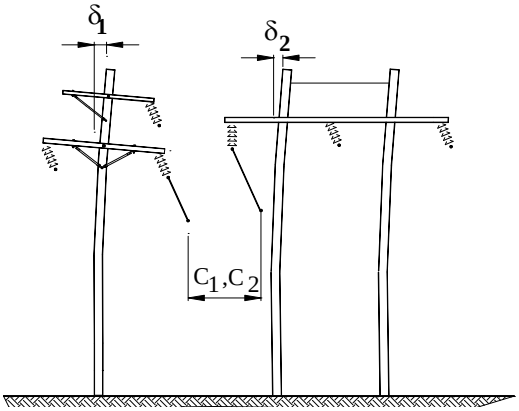


FIGURE 5-10: CLEARANCE BETWEEN CONDUCTORS OF ONE LINE TO CONDUCTOR OF ANOTHER LINE

5.6.2 Separation Between Lines as Dictated by Minimum Clearance of Conductors From One Line to the Supporting Structure of Another: The horizontal clearance of a phase conductor of one line to the supporting structure of another when the conductor and insulator are displaced by a 6 psf wind at 60°F final sag should meet Equation 5-7.

$$C_3 = 6' + \frac{.4}{12}\left(kV_{LG} - 22\right) + \left(\delta_1 - \delta_2\right) \qquad \text{Eq. 5-7}$$

where:

kV_{LG} = the maximum line-to-ground voltage in kV
C_3 = the clearance of conductors of one line to structure of another in feet

Other symbols are defined in Figure 5-1.

Additional 1.5 feet have been added to the NESC clearance and included in equation 5-7 to obtain the design clearance 'C_3'.

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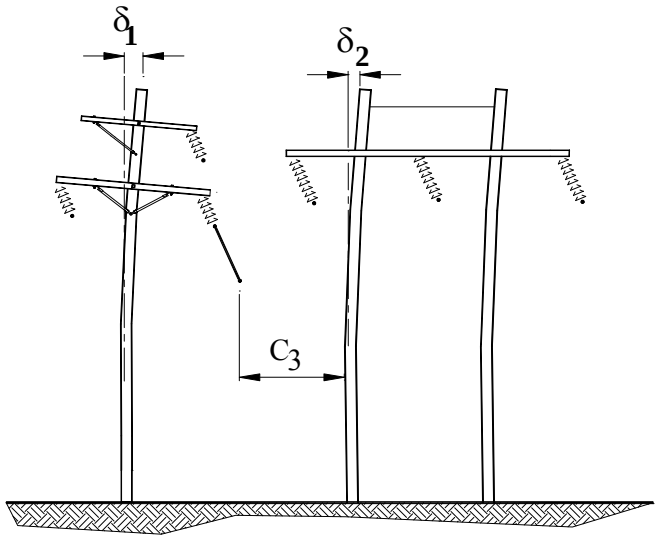

FIGURE 5-11: CLEARANCE BETWEEN CONDUCTORS OF ONE LINE AND STRUCTURE OF ANOTHER

The separation between lines will depend upon the spans and sags of the lines as well as how structures of one line match up with structures of another. In order to avoid the unreasonable task of determining separation of structures span-by-span, a standard separation value should be used, based on a worst case analysis. Thus if structures of one line do not always line up with those of the other, the separation determined in section 5.6.2 should be based on the assumption that the structure of one line is located next to the mid-span point of the line that has the most sag.

5.6.3 Other Factors: Galloping should be taken into account in determining line separation. In fact, it may be the determining factor in line separation. See Chapter 6 for a discussion of galloping.

Standard phase spacing should also be taken into account. For example, if two lines of the same voltage using the same type structures and phase conductors are on a single ROW, a logical separation of the two closest phases of the two lines should be at least the standard phase separation of the structure.

5.6.4 Altitude Greater than 3300 Feet: If the altitude at which the lines included in the design are installed greater than 3300 feet, NESC Section 23 rules provide additional separation requirements.

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6. CLEARANCES BETWEEN CONDUCTORS AND BETWEEN CONDUCTORS AND OVERHEAD GROUND WIRES

6.1 General: The preliminary comments and assumptions of Chapter 4, section 4.2, also apply to this chapter.

This chapter considers design limits related to conductor separation. It is assumed that only standard agency structures will be used, thus making it unnecessary to check conductor separation at structures. Therefore, the only separation values left to consider are those related to span length and conductor sags.

Maximum span lengths may be controlled by conductor separation. Other factors which may limit span length, but are not covered in this chapter, are structure strength, insulator strength, and ground clearance.

6.2 Maximum Span as Limited by Horizontal Conductor Separation: Sufficient horizontal separation between phases is necessary to prevent swinging contacts and flashovers between conductors where there is insufficient vertical separation.

6.2.1 Situations Under Which Maximum Span as Limited by Horizontal Separation are to be Met:

If the vertical separation (regardless of horizontal displacement) of phase conductors of the same or different circuit(s) at the structure is less than the appropriate values provided in Table 6-1,then the recommendations in sections 6.2.2, 6.2.3, and 6.2.4 of this section should be met.

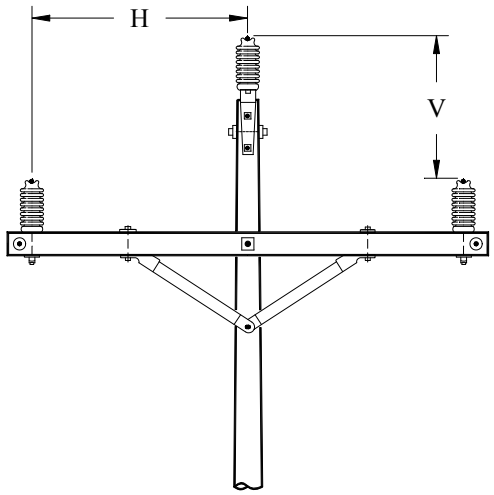


FIGURE 6-1: EXAMPLE OF VERTICAL AND HORIZONTAL SEPARATION VALUES

6.2.2 Horizontal Separation Recommendations: Equation 6-1 gives an horizontal phase spacing (relative to conductor sag, and thus indirectly to span length) that should be sufficient to prevent swinging contacts or flashovers between phases of the same or different circuits.

$$H = (0.025)kV + F_c\sqrt{S_f} + \ell_i(\sin\phi_{\max}) \qquad \text{Eq. 6-1}$$

where:

H = horizontal separation between the phase conductors at the structure in feet.

kV = (phases of the same circuit) the nominal line-to-line voltage in 1000's of volts for 34.5 and 46 kV and 1.05 times the nominal voltage in 1000's of volts for higher voltages

kV = (phases of different circuits) 1.05 times the magnitude of the voltage vector between the phases in 1000's of volts. kV should never be less than 1.05 times the nominal line-to-ground voltage in 1000's of volts of the higher voltage circuit involved regardless of how the voltage vectors add up. The voltage between the phases should be taken as the sum of the two line-to-ground voltages, based on 1.05 times nominal voltage.

F_C = experience factor

$Ø_{max}$ = maximum 6 psf insulator swing angle for the structure in question. See Chapter 7 of this bulletin.

S_f = final sag of the conductor at 60°F, no load, in feet

ℓ_i = length of the insulator string in feet, $\ell_i = 0$ for post or restrained suspension insulators

V = vertical separation between phase conductors at the structure in feet

The experience factor (F_C) may vary from a minimum of 0.67 to a maximum of 1.4, depending upon how severe the wind and ice conditions are judged to be. The following are values of F_C that have proved to be satisfactory in the past.

$F_C = 1.15$ for the light loading zone
$F_C = 1.2$ for the medium loading zone
$F_C = 1.25$ for the heavy loading zone

Any value of F_C in the 0.67 to 1.4 range may be used if it is thought to be reasonable and prudent. There has been significant favorable experience with larger conductor sizes that have horizontal spacing based on an F_C factor of 0.67. Therefore, F_C factor values significantly less than the values listed above may be appropriate. If F_C values less than those given above are used, careful attention should be paid to galloping as a possible limiting condition on the maximum span length.

TABLE 6-1
RECOMMENDED VERTICAL SEPARATION IN FEET BETWEEN PHASES
OF THE SAME OR DIFFERENT CIRCUITS ATTACHED TO THE SAME STRUCTURE
(For separations less than those shown, Equation 6-1 applies) (See Notes E & F)

Nominal voltage, Line-to-Line Voltage in kV	**34.5 & 46**	**69**	**115**	**138**	**161**	**230**
Max. Operating Voltage, Phase to Phase, kV	----	72.5	120.8	144.9	169.1	241.5
Max. Operating Voltage, Phase to Ground, kV	----	41.8	69.7	83.7	97.6	139.4
Vertical Separation	Separation in feet					
Minimum Vertical Separation at Support						
1. Phases of the same circuit (Note A) (Based on NESC Table 235-5)	3.2	4.0	5.6	6.4	7.2	9.6
2. Phases of different circuits (Notes B & D) (Based on NESC Table 235-5,footnote 7 criteria for different utilities)	5.4	6.3	8.2	9.1	10.1	12.8
3. Phase conductors and overhead ground wires (Based on NESC 235C and 233C3)	2.5	2.9	3.9	4.3	4.8	6.4
Minimum Vertical Separation in Span						
4. Phases of the same circuit (Notes A & G) (Based on NESC Table 235-5), H ≥ 1.0 ft., Figure 6-4	2.5	3.3	4.9	5.7	6.5	9.0
5. Phases of different circuits (Notes C, D & G) (Based on NESC Table 235-5, footnote 7 **criteria for different utilities** NESC Rule 235C2b.), H ≥ 1.0 ft., Figure 6-4	4.2	5.2	7.0	7.9	8.9	11.7
6. Phase conductors and overhead ground wires (H ≥ 1.0 ft., Figure 6-4), Notes D & G	1.5	2.1	3.0	3.6	4.0	5.4
ALTITUDE CORRECTION TO BE ADDED TO VALUES IN CATEGORY '2' ABOVE (NONE REQUIRED FOR CATEGORY '1'):						
Additional feet of clearance per 1000 feet of altitude above 3300 feet	.02	.02	.05	.07	.08	.12

Notes:

(A) There are no NESC values specified for vertical separation of conductors of the same circuit for voltages above 50 kV line-to-line.

(B) Assumes both circuits have the same nominal voltage. If they do not, the vertical separation can be determined using Equation 6-2 below.

$$V = \frac{40}{12} + \frac{.4}{12}\left(kV_{LG1} + kV_{LG2} - 8.7\right) + \frac{6}{12}\left(NoteD\right) \qquad \text{Eq. 6-2}$$

where:

kV_{LG1} = Line to ground voltage circuit one, kilovolts.

kV_{LG2} = Line to ground voltage circuit two, kilovolts.

TABLE 6-1 (continued)
RECOMMENDED VERTICAL SEPARATION IN FEET BETWEEN PHASES
OF THE SAME OR DIFFERENT CIRCUITS ATTACHED TO THE SAME STRUCTURE
(For separations less than those shown, Equation 6-1 applies) (See Notes E & F)

(C) Assumes both circuits have the same nominal voltage. If they do not, the vertical separation can be determined using Equation 6-2a below.

$$V = .75\left[\frac{40}{12} + \frac{.4}{12}(50 - 8.7)\right] + \frac{.4}{12}\left(kV_{LG1} + kV_{LG2} - 50\right) + \frac{6}{12}\left(NoteD\right) \quad \text{Eq. 6-2a}$$

(D) An additional 0.5 feet of clearance is added to the NESC clearance to obtain the recommended design clearances.

(E) The values in this table are not recommended as minimum vertical separations at the structure for non-standard agency structures. They are intended only to be used on standard agency structures to determine whether or not horizontal separation calculations are required.

(F) The upper conductor is at final sag at the maximum operating temperature and the lower conductor is at final sag at the same ambient conditions as the upper conductor without electrical loading and without ice loading; **or**, the upper conductor is at final sag at 32º with radial ice from either the medium loading district or the heavy loading district and the lower conductor is at final sag at 32ºF.

(G) In areas subjected to icing, an additional 2.0 feet of clearance should be added to the above clearances when conductors or wires are directly over one another or have less than a one foot horizontal offset. See section 6.3 of this bulletin.

6.2.3 <u>Additional Horizontal Separation Equation</u>: Equation 6-3 below, commonly known as the Percy Thomas formula, may be used in addition to (but not instead of) equation 6-1 for determining the horizontal separation between the phases at the structure. Equation 6-3 takes into account the weight, diameter, sag, and span length of the conductor.

$$H = (.025)kV + \frac{(E_c)(d_c)(S_p)}{w_c} + \frac{\ell_i}{2} \quad \text{Eq. 6-3}$$

where:

d_c = conductor diameter in inches
w_c = weight of conductor in lbs/ft.
E_c = an experience factor. It is generally recommended that (E_c) be larger than 1.25.
S_p = sag of conductor at 60°F, expressed as a percent of span length

All other symbols are as previously defined.

By using the Thomas formula to determine values of E_c, the spacing of conductors on lines which have operated successfully in a locality can be examined. These values of E_c may be helpful in determining other safe spacings.

6.2.4 <u>Maximum Span Based on Horizontal Separation at the Structure</u>: Equation 6-1 can be rewritten and combined with Equation 10-1 (Chapter 10) to yield the maximum allowable

span, given the horizontal separation at the structure and the sag and length of the ruling span. See Chapter 9 for a discussion of ruling span.

$$L_{\max} = (RS)\left(\frac{H - (.025)kV - \ell_i \sin\phi_{\max}}{F_c\sqrt{S_{RS}}}\right) \qquad \text{Eq. 6-4}$$

where:

L_{max} = maximum span as limited by conductor separation in feet
RS = length of ruling span in feet
S_{RS} = sag of the ruling span at 60°F final sag in feet

Other symbols are as previously defined for Eq. 6-1.

6.2.5 <u>Maximum Span Based on Vertical Separation</u>: Since vertical separation is related to the relative sags of the phase conductors involved, and since sags are related to span length, a maximum span as limited by vertical separation can be determined. The formula for the maximum span as limited by vertical separation is:

$$L_{\max} = (RS)\sqrt{\frac{D_v - B}{S_\ell - S_u}} \qquad \text{Eq. 6-5}$$

where:

L_{max} = maximum allowable span in feet
D_V = required vertical separation at mid-span in feet
B = vertical separation at supports in feet
S_ℓ = sag of lower conductor in feet without ice
S_u = sag of upper conductor wire in feet with ice
RS = ruling span in feet

6.2.6 <u>Example of Clearance Calculations</u>: The following example demonstrates the derivation of the vertical separation at a support for phases of different circuits in Tables 6-1 of this bulletin.

To determine the vertical separation of a 115 kV line to another 115 kV circuit, the clearance is based on NESC Table 235-5 and NESC Rule 235.

At the support, phases of different circuits:

NESC Vertical Separation = 40 inches/12 in./ft + .4(kV_{L-G} + kV_{L-G} – 8.7)/12 ft.
= 3.333 ft. + .4(69.7+69.7-8.7)/12 ft.
= 3.33 ft.+ 4.36 ft.
NESC Vertical Separation = 7.69 feet

Recommended
Vertical Separation = NESC Vertical Separation + suggested Adder
= 7.69 feet + 0.5 feet
= 8.19 feet (8.2 feet in Table 6-1)

In the span, phases of different circuits:

$$\text{NESC Vertical Separation} = 0.75\left[\frac{40}{12}+\frac{.4}{12}(50-8.7)\right]+\frac{.4}{12}\left(kV_{LG1}+kV_{LG2}-50\right)$$

= 0.75(3.33+1.37) ft + (.4/12)(69.7+69.7-50) feet
= 3.53 ft. + 2.98 feet

NESC Vertical Separation in the Span = 6.51 feet

Recommended Clearance = NESC Vertical Separation + suggested Adder
= 6.51 feet + .5 feet
= 7.01 feet (7.0 feet in Table 6-1)

6.3 Maximum Span as Limited by Conductor Separation Under Differential Ice Loading Conditions

6.3.1 General: There is a tendency among conductors covered with ice, for the conductor closest to the ground to drop its ice first. Upon unloading its ice the lower conductor may jump up toward the upper conductor, possibly resulting in a temporary short circuit. After the lower conductor recovers from its initial ice-jump it may settle into a position with less sag than before, which may persist for long periods of time. If the upper conductor has not dropped its ice, the reduced separation may result in a flashover between phases.

The clearance recommendations provided in paragraph 6.3.2 of this section are intended to insure that sufficient separation will be maintained during differential ice loading conditions with an approach towards providing clearance for the ice-jump.

6.3.2 Clearance Recommendations: The minimum vertical distance (D_v) in span between phase conductors, and between phase conductors and overhead ground wires under differential ice loading conditions, are provided in Table 6-1. These vertical separations in span are recommended in cases where the horizontal separation between conductors (H) is greater than one foot (H ≥1.0 ft). When conductors or wires are directly over one another or have less than a 1 foot horizontal offset, it is recommended that an additional 2 feet of clearance be added to the values given in Table 6-1. The purpose of this requirement is to improve the performance of the line under ice-jump conditions. It has been found that a horizontal offset of as little as 1 foot significantly lessens the ice-jump problem. Figure 6-4 indicates the horizontal and vertical components of clearance and their relationship.

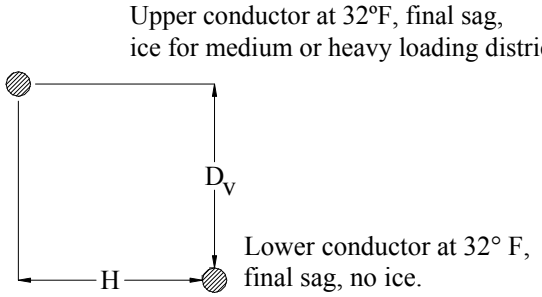


FIGURE 6-2: MINIMUM DISTANCE BETWEEN CONDUCTORS

6.3.3 Conditions Under Which Clearances Apply: Lines should be designed so that clearances are considered with the upper conductor at 32°F, final sag, and a radial thickness of ice equal to the ice thickness from either the medium loading district or the heavy loading district. The lower conductor should be at 32°F, final sag, no ice. The designer is reminded to check clearances for the upper conductor at the maximum operating temperature (no wind) and the lower conductor at ambient temperature (see Note F of Table 6-1).

6.4 Overhead Ground Wire Sags and Clearances: In addition to checking clearances between the overhead ground wire (OHGW) and phase conductors under differential ice loading conditions, it is also important that the relative sags of the phase conductors and the OHGW be coordinated so that under more commonly occurring conditions, there will be a reasonably low chance of a mid-span flashover. Adequate midspan separation is usually assured for standard agency structures by keeping the sag of the OHGW at 60°F initial sag, no load conditions to 80 percent of the phase conductors under the same conditions.

6.5 Maximum Span as Limited by Galloping

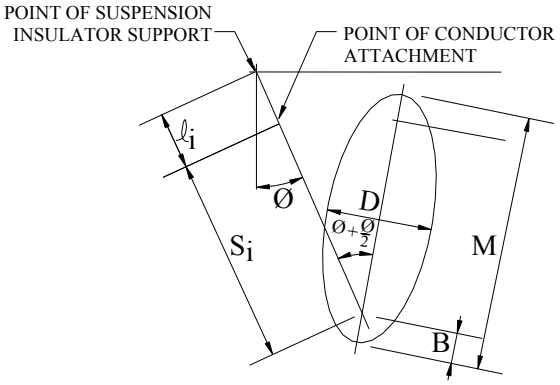
6.5.1 The Galloping Phenomenon: Galloping, sometimes called dancing, is a phenomenon where the transmission line conductors vibrate with very large amplitudes. This movement of conductors may result in: (1) contact between phase conductors or between phase conductors and overhead ground wires, resulting in electrical outages and conductor burning, (2) conductor failure at support point due to the violent stress caused by galloping, (3) possible structure damage, and (4) excessive conductor sag due to the overstressing of conductors.

Galloping usually occurs only when a steady, moderate wind blows over a conductor covered by a layer of ice deposited by freezing rain, mist or sleet. The coating may vary from a very thin glaze on one side to a solid three-inch cover and may give the conductor a slightly out-of-round, elliptical, or quasi-airfoil shape. The wind blowing over this irregular shape results in aerodynamic lift which causes the conductor to gallop. The driving wind can be anything between 5 to 45 miles per hour at an angle to the line of 10 to 90 degrees and may be unsteady in velocity or direction.

During galloping, the conductors oscillate elliptically at frequencies on the order of 1-Hz or less with vertical amplitudes of several feet. Sometimes two loops appear, superimposed on one basic loop. Single-loop galloping rarely occurs in spans over 600 to 700 feet. This is fortunate since it would be impractical to provide clearances large enough in long spans to prevent the possibility of contact between phases. In double-loop galloping, the maximum amplitude usually occurs at the quarter span points and is smaller than that resulting from single-loop galloping. There are several measures that can be incorporated at the design stage of a line to reduce potential conductor contacts caused by galloping, such as designing the line to have shorter spans, or increased phase separation. The H-frame structures provide very good phase spacing for reducing galloping contacts.

6.5.2 Galloping Considerations in the Design of Transmission Lines: In areas where galloping is either historically known to occur or is expected, designers should indicate design measures that will minimize galloping and galloping problems, especially conductor contacts. The primary tool for assuring absence of conductor contacts is to superimpose Lissajous ellipses over a scaled diagram of the structure to indicate the theoretical path of a galloping conductor. See Figures 6-3 and 6-4. To avoid contact between phase conductors or between phase conductors and overhead ground wires, none of the conductor ellipses should touch one another. However, if galloping is expected to be infrequent and of minimal severity, there may be situations where allowing ellipses to overlap may be the favored design choice when economics are considered.

FIGURE 6-3: GUIDE FOR PREPARATION OF LISSAJOUS ELLIPSES



$$\phi = \tan^{-1}\left(\frac{p_c}{w_c}\right) \qquad \text{Eq. 6-6}$$

	Single Loop	Double Loop
Major Axis 'M'	$M = 1.25\,S_i + 1.0$ Eq. 6-7	$M = 1.0 + \sqrt{\frac{3a\left(L + \frac{8S_i^2}{3L} - 2a\right)}{8}}$ Eq. 6-8 where $a = \sqrt{\left(\frac{L}{2}\right)^2 + S_i^2}$
Distance 'B'	$B = 0.25\,S_i$ Eq. 6-9	$B = 0.2M$ Eq. 6-10
Minor Axis 'D'	$D = 0.4M$ Eq. 6-11	$D = 2\sqrt{M - 1.0}$ Eq. 6-12

Where:

p_c = wind load per unit length on iced conductor in lbs/ft. Assume a 2 psf wind.
w_c = weight per unit length of conductor plus 1/2 in. of radial ice, lbs/ft
L = span length in feet.
M = major axis of Lissajous ellipses in feet.
S_i = final sag of conductor with 1/2 in. of radial ice, no wind, at 32°F, in feet.
D = minor axis of Lissajous ellipses in feet.
B,Ø = as defined in figure above

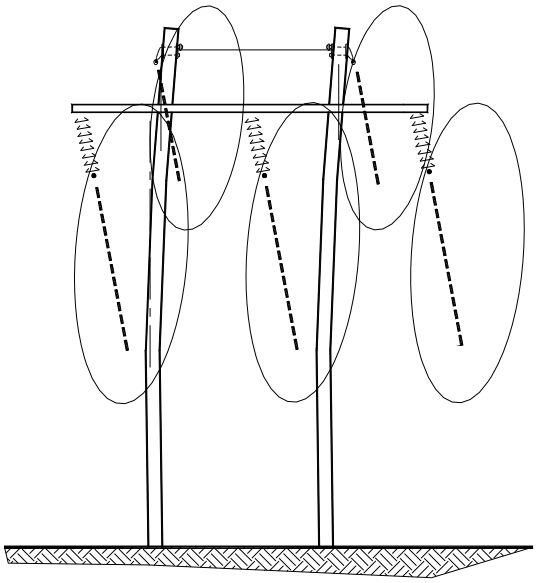


FIGURE 6-4: SINGLE LOOP GALLOPING ANALYSIS

6.6 <u>Clearance Between Conductors in a Crossarm to Vertical Construction Span</u>:
Conductor contacts in spans changing from crossarm to vertical type construction may be reduced by proper phase arrangement and by limiting span lengths. Limiting span lengths well below the average span lengths is particularly important in areas where ice and sleet conditions can be expected to occur. See Figure 6-5.

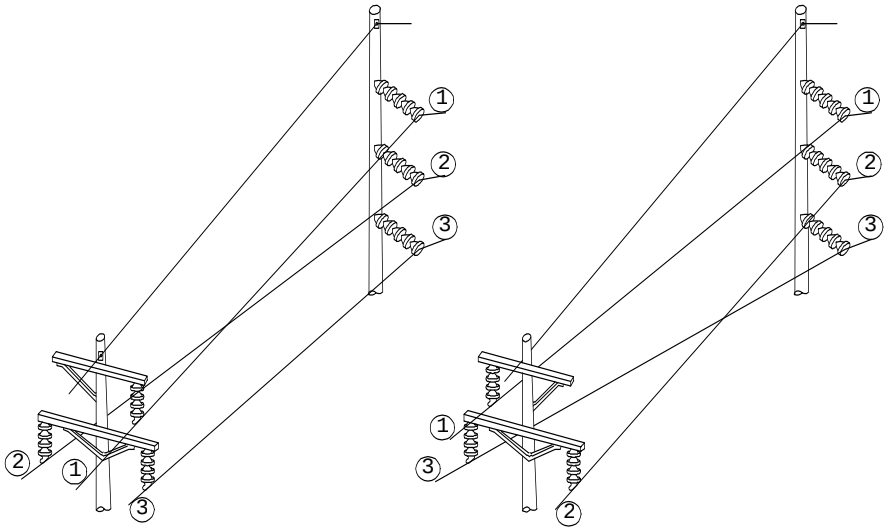


FIGURE 6-5: PROPER PHASE ARRANGEMENTS FOR CROSSARM TO VERTICAL CONSTRUCTION

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7. INSULATOR SWING AND CLEARANCES OF CONDUCTORS FROM SUPPORTING STRUCTURES

7.1 Introduction: Suspension insulator strings supporting transmission conductors, either at tangent or angle structures, are usually free to swing about their points of support. Therefore, it is necessary to ensure that when the insulators do swing, clearances are maintained to structures and guy wires. The amount of swing varies with such factors as: conductor tension, temperature, wind velocity, insulator weight, ratio of weight span to wind span, and line angle.

The force due to line angle will cause suspension strings to swing in the direction of the line angle of the structure. Wind blowing on the conductor span will exert a force in the direction of the wind. These two forces may act either in the same direction or in opposite, the algebraic sum thereby determining the net swing direction. Line angle forces and wind forces also interact with the vertical forces of the conductor weight and insulator string weight. The vector sum of these forces determines the net angle from the vertical axis to which the insulator string will swing. This net insulator swing angle should be calculated for several key weather conditions so that corresponding phase-to-ground clearances may be checked on a particular pole-top arrangement.

The purpose of this chapter is to explain how insulator swing application guides called swing charts are prepared. Chapter 10 explains how these charts are used in laying out a line.

7.2 Clearances and Their Application: Table 7-1 provides information on three sets of clearances that can ensure proper separation between conductors and structures or guys under various weather conditions. Figure 7-1 illustrates the various situations in which the clearances are to be applied.

7.2.1 No-Wind Clearance: The no wind clearance provides a balanced insulation system in which the insulating value of the air gap is approximately the same as that of the insulator string for a tangent structure. (See Table 8-1 for insulation levels. Note that tangent structures do not include the extra insulators used with angle structures).

Conditions at which no-wind clearances are to be maintained follow:

- Wind: Assume no wind.
- Temperature: Assume a temperature of 60°F. See Figure 7-1 for conductor condition. The engineer may also want to evaluate clearances at cold conditions (such as -20°F initial sag) and hot conditions (such as 167°F final sag).

7.2.2 Moderate Wind Clearance: This clearance is the minimum clearance that should be maintained under conditions that are expected to occur occasionally. A typical condition may be the wind that reoccurs no less than once every two years (probability of occurrence no more than 50 percent). Clearance values for moderate wind clearance conditions will have a lower flashover value than clearance values for the no-wind condition. These lower clearance values are acceptable because under moderate wind conditions, the specified clearance will be sufficient to withstand most of the severe voltage stress situations for wind conditions that are not expected to occur often.

There are different clearance requirements to the structure than to anchor guys. See Table 7-1, moderate wind, for differences. Also, note that Table 7-1 requires that additional clearance must be provided if the altitude is above 3300 feet.

Conditions at which moderate wind clearances are to be maintained follow:

- Wind: Assume a wind of at least 6 psf blowing in the direction shown in Figure 7-1. Higher wind pressures can be used if judgment and experience deem them to be necessary. However, the use of excessively high wind values could result in a design that is overly restrictive and costly. It is recommended that wind pressure values of no higher than 9 psf (60 mph) be used for the moderate wind clearance design unless special circumstances exist.

- Temperature: Temperature conditions under which the clearances are to be maintained depend upon the type of structure. A temperature of no more than 32°F should be used for tangent and small angle structures where the insulator string is suspended from a crossarm. A lower temperature value should be used where such a temperature can be reasonably expected to occur in conjunction with the wind value assumed. It should be borne in mind, however, the insulator swing will increase at lower temperatures because conductor tensions increase. Therefore, in choosing a temperature lower than 32°F, one should weigh the increase in conservatism of line design against the increase or decrease in line cost. NESC Rule235 requires a temperature no higher than 60°F final tension.

  A temperature of 60°F should be used for angle structures where the force due to change in direction of the conductor holds the insulator string away from the structure. Even if the maximum conductor temperature is significantly greater than 60°F, a higher temperature need not be used as an assumed wind value of 40 mph (6 psf)) has quite a cooling effect.

  Assume final sag conditions for 60°F temperature and initial sag conditions for 32°F.

7.2.3 High Wind Clearance: This is the minimum clearance that should be maintained under high wind conditions that are expected to occur very rarely. The clearances provide enough of an air gap to withstand a 60 Hz flashover but not much more. Choice of such values is based on the philosophy that under very rare high wind conditions, the line should not flashover due to the 60 Hz voltage.

Conditions under which high wind clearances are to be maintained are:

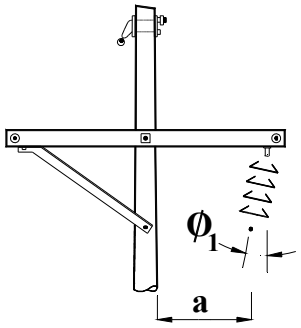
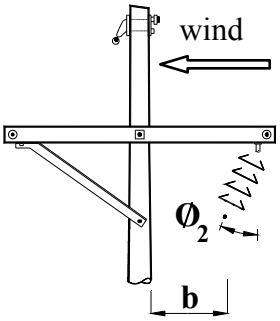
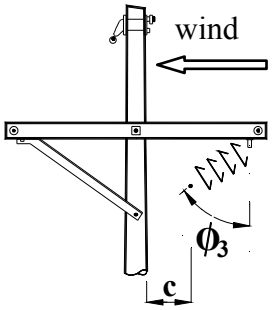
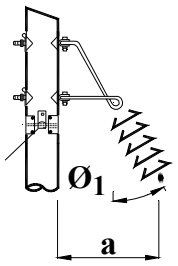
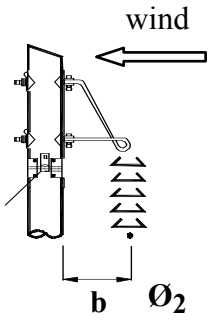
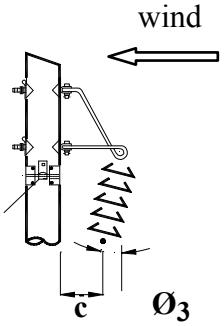
- Wind: The minimum assumed wind value should be at least the 10-year mean recurrence interval wind blowing in the direction shown in Figure 7-1. More wind may be assumed if deemed appropriate.

- Temperature: The temperature assumed should be that temperature at which the wind is expected to occur. The conductor should be assumed to be at final tension conditions.

To determine the velocity of the wind for a 10 year return period, the following factors should be applied to the 50 year peak gust wind speed (See Figures 11-2a, b, c and d in Chapter 11).

V = 85 to100 mph, Continental U.S.	Alaska	V > 100 mph (hurricane)
0.84	0.87	0.74

FIGURE 7-1: ILLUSTRATION OF STRUCTURE INSULATOR SWING ANGLE LIMITS AND CONDITIONS* UNDER WHICH THEY APPLY (EXCLUDES BACKSWING)

TANGENT AND SMALL ANGLE STRUCTURES	**No Wind Insulator Swing**	**Moderate Wind Insulator Swing**	**High Wind Insulator Swing**
Conditions* at which clearances are to be maintained			
• Line angle	Force due ← to line angle (if any)	Force due ← to line angle (if any)	Force due ← to line angle (if any)
• Wind force	0	6 psf minimum	10 year mean wind, recommended value
• Temperature	60ºF	32ºF or lower	Temp. at which wind value is expected
• Conductor tension	Final tension	Initial tension	Final tension
MEDIUM AND LARGE ANGLE STRUCTURES **Conditions* at which clearances are to be maintained**			
• Line angle	Force due → to line angle	Force due → to line angle	Force due → to line angle
• Wind force	0	6 psf minimum	10 year mean wind, min.recommended value
• Temperature	60ºF	60ºF or lower	Temp. at which wind value is expected
• Conductor tension	Final tension	Final tension	Final tension

a = No wind clearance b = Moderate wind clearance c = High wind clearance
*See text for full explanation of conditions.

TABLE 7-1
RECOMMENDED MINIMUM CLEARANCES IN INCHES AT
CONDUCTOR TO SURFACE OF STRUCTURE OR GUY WIRES

Nominal voltage, Phase to Phase, kV	**34.5**	**46**	**69**	**115**	**138**	**161**	**230**
Standard Number of 5-3/4"x10" Insulators on Tangent Structures	**3**	**3**	**4**	**7**	**8**	**10**	**12**
Max. Operating Voltage, Phase to Phase, kV	34.5	46	72.5	120.8	144.9	169.1	241.5
Max. Operating Voltage, Phase to Ground, kV	19.9	26.6	41.8	69.7	83.7	97.6	139.4
			Clearance in inches				
No Wind Clearance (Not NESC)							
Min. clearance to structure or guy at no wind in inches Notes A, B	19	19	25	42	48	60	71
Moderate Wind Clearance (NESC Table 235-6)							
Min. clear. to structure at 6 psf of wind in inches. Notes C, D	9	11	16	26	30	35	50
Min. clear. to jointly used structures and a 6 psf of wind in inches. Notes C, D	11	13	18	28	32	37	52
Min. clearance to anchor guys at 6 psf in inches Notes C, D	13	16	22	34	40	46	64
High Wind Clearance (Not NESC)							
Min. clearance to structure or guy at high wind in inches	3	3	5	10	12	14	20

Notes:

(A) If insulators in excess of the standard number for tangent structures are used, the no wind clearance value shown should be increased by 6 in. for each additional bell. If the excess insulators are needed for contamination purposes, this additional clearance is not necessary.

(B) For post insulators, the no wind clearance to structure or guy is the length of the post insulator.

(C) A higher wind may be assumed if deemed necessary.

(D) The following values should be added as appropriate where the altitude exceeds 3300 feet

Additional inches of clearance per 1000 feet of altitude above 3300 feet

Voltage, kV	34.5	46	69	115	138	161	230
Clearance to structure	0	0	.14	.43	.57	.72	1.15
Clearance to anchor guy	0	0	.17	.54	.72	.90	1.44

7.2.4 Example of Clearance Calculations: The following examples demonstrate the derivation of the minimum clearance to anchor guys at 6 psf.

To determine the minimum clearance of a 115 kV line to an anchor guy (Table 7-1) at 6 psf, the clearance is based on NESC Table 235-6 and NESC Rule 235E.

NESC Clear. in any direction. = NESC Basic Clearance(Table 235-6) + .25(kV_{L-L} – 50)
= 16 inches + .25(120.8-50) inches
= 16 inches + 17.7 inches
NESC Clear. in any direction. = 33.7 inches (clearance in Table 7-1is 34 inches)

7.3 Backswing: Insulator swing considerations are illustrated in Figure 7-1. For angle structures where the insulator string is attached to the crossarm, the most severe condition is usually where the force of the wind and the force of the line angle are acting in the same direction. However, for small angle structures, it is possible that the limiting swing condition may be when the wind force is in a direction opposite of that due to the force of the line angle. This situation is called backswing, as it is a swing in a direction opposite of that in which the insulator is pulled by the line angle force. Figure 7-2 illustrates backswing.

When calculating backswing, it is necessary to assume those conditions that would tend to make the swing worse, which usually is low conductor tension or small line angles. It is recommended that the temperature conditions for large angle structures in Figure 7-1 be used, as they result in lower conductor tensions.

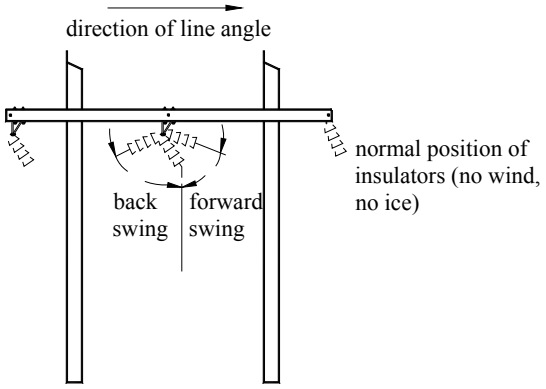


FIGURE 7-2: FORWARD AND BACKWARD SWING ANGLES

7.4 Structure Insulator Swing Values: Table 7-2 provides the allowable insulator swing angle values for some of the most often used standard agency tangent structures. These values represent the maximum angle from the vertical that an insulator string of the indicated number of standard bells may swing in toward the structure without violating the clearance category recommendation indicated at the top of each column. For tangent structures, the most restrictive angle for the particular clearance category for the entire structure is given. Thus, for an asymmetrical tangent structure (TS-1 for instance) where the allowable swing angle depends upon whether the insulators are assumed to be displaced to the right or left, the use of the most restrictive value means that the orientation of the structures with respect to the line angle need not be considered. For certain angle structures the insulator string has to be swung away from the structure in order to maintain the necessary clearance. These situations usually occur for large angle structures where the insulator string is attached directly to the pole or to a bracket on the pole and where the force due to the change in direction of the conductors is relied upon to hold the conductors away from the structure.

TABLE 7-2
INSULATOR SWING ANGLE VALUES IN DEGREES
(For insulator string with ball hooks)
(For insulator swing of other structures, see Appendix J)

Structure and Voltage	Number of Insulators	No Wind Swing Angle	Moderate Wind Swing Angle	High Wind Swing Angle
69 kV				
TS-1, TS-1X	4	20.0	38.5	74.0
TSZ-1, TSZ-2	4	41.7	61.2	82.6
TH-1,TH-1G	4	35.6	61.2	85.6
115 kV – TH-1A	7	28.3	58.7	80.8
161 kV – TH-10	10	16.4	53.2	77.7
230 kV – TH-230	12	16.5	47.5	74.8

7.5 <u>Line Design and Structure Clearances</u>: Insulator swing has a key effect on acceptable horizontal to vertical span ratios. Under a given set of wind and temperature conditions, an insulator string on a structure will swing at an angle toward the structure a given number of degrees. The angle of this swing is related to a ratio of horizontal to vertical forces on the insulator string. A relationship between the horizontal span, the vertical span, and if applicable, the line angle can then be developed for the structure, conductor, and weather. Horizontal and vertical spans are explained in Figure 7-4.

The acceptable limits of horizontal to vertical span ratios are plotted on a chart called an insulator swing chart. Such a chart can be easily used for checking or plotting out plan and profile sheets. Figures 7-3 and 7-5 show simplified insulator swing charts for the moderate wind condition only. There is one significant difference between the chart for tangent structures, and the chart for angle (running corner) structures. In Figure 7-3 for a typical tangent structure, the greater the vertical span for a fixed horizontal span the less swing occurs. The reverse is true for chart of Figure 7-5 for a typical angle structure. This occurs because the swing chart in Figure 7-5 is for a large angle structure where the force of the line angle is used to pull the insulator string away from the structure. As such, the less vertical force there is from the weight span, the greater the horizontal span can be.

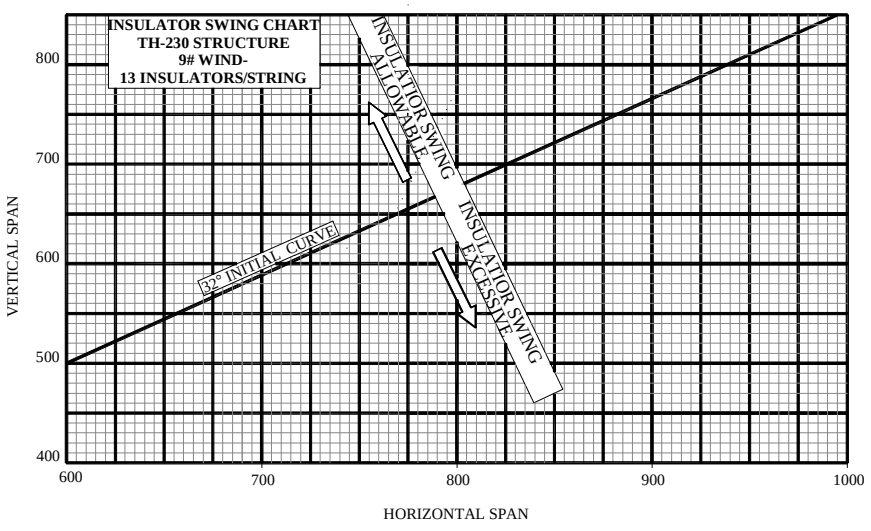
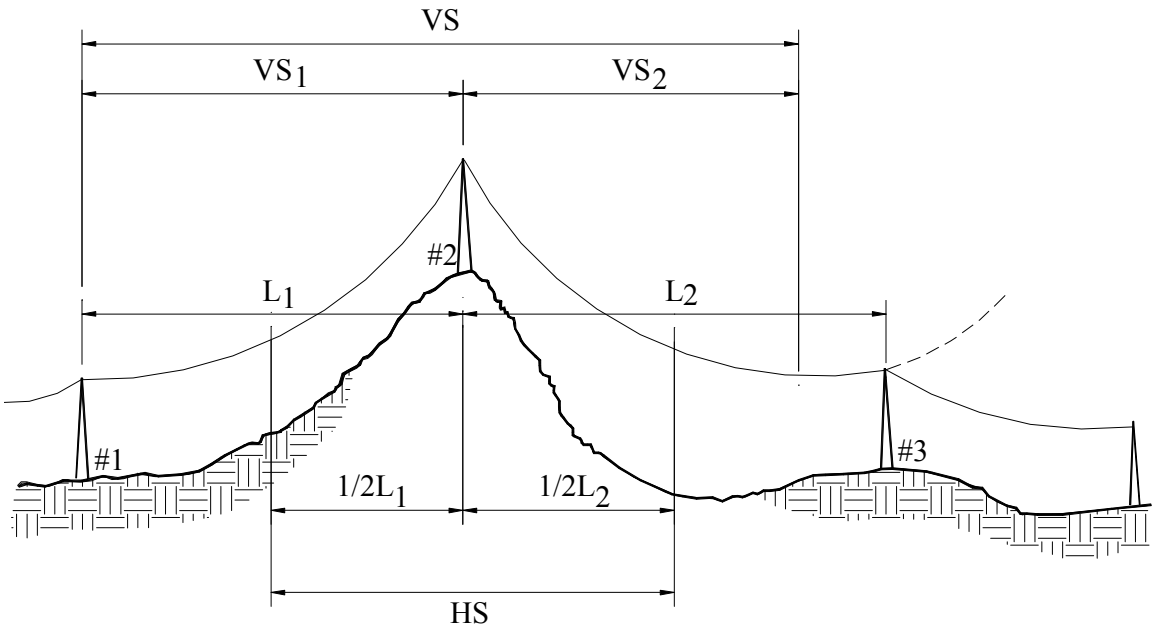


FIGURE 7-3: TYPICAL INSULATOR SWING CHART FOR A TH-230 TANGENT



L = span,

L_1 - span from structure 1 to 2
L_2 = span from structure 2 to 3

HS = horizontal span
VS = vertical span

Span

Span is the horizontal distance from one structure to an adjacent structure along the line.

Vertical Span

The vertical span (sometimes called the weight span) is the horizontal distance between the lowest points on the sag curve of two adjacent spans. The maximum sag point of a span may actually fall outside the span. The vertical span length times the weight of the loaded conductor per foot will yield the vertical force per conductor bearing down upon the structure and insulators

Horizontal Span

The horizontal span (sometimes called the wind span) is the horizontal distance between the mid-span points of adjacent spans. Thus, twice the horizontal span is equal to the sum of the adjacent spans. The horizontal span length times the wind force per foot on the conductor will yield the total horizontal force per conductor on the insulators and structure.

FIGURE 7-4: HORIZONTAL AND VERTICAL SPANS

The 'no wind' insulator swing criteria will not be a limiting condition on tangent structures as long as the line direction does not change and create an angle in the line. If an angle is turned, it is possible that the 'no wind' condition might control. The other two criteria may control under any circumstance. However, the high wind criteria will be significant in those areas where unusually high winds can be expected. Thus, all three conditions specified need to be checked.

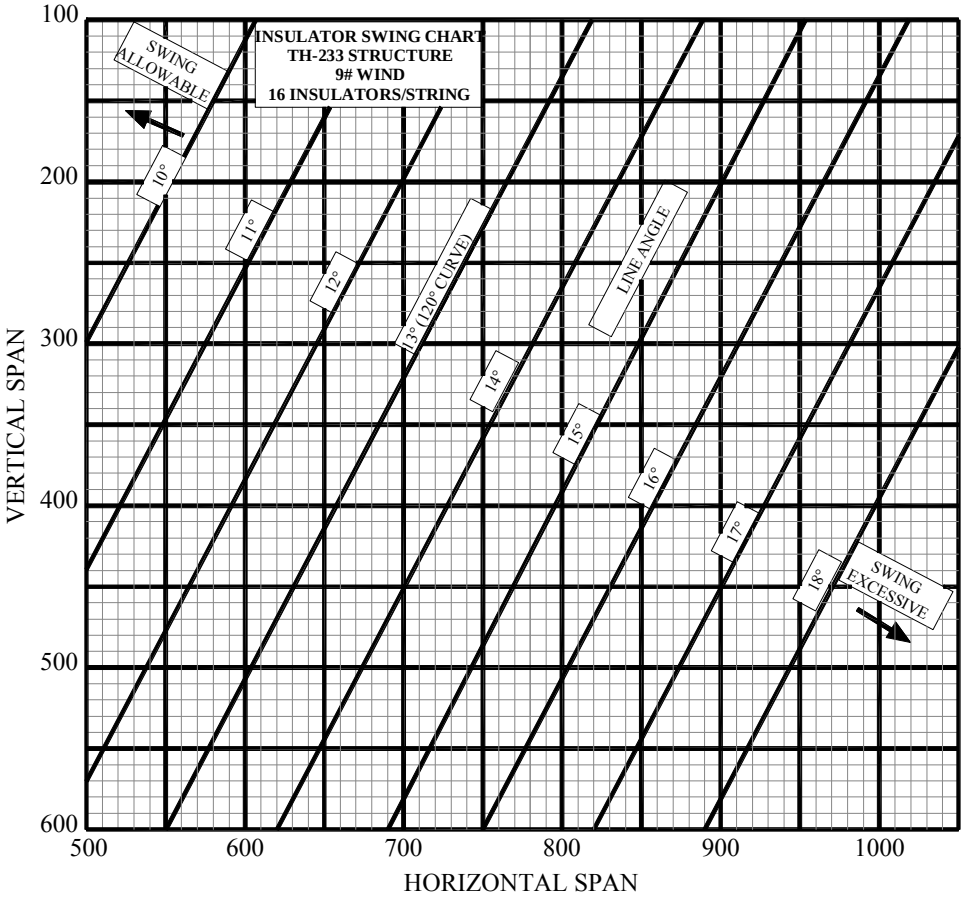


FIGURE 7-5: TYPICAL INSULATOR SWING CHART FOR A TH-233 MEDIUM ANGLE STRUCTURE (Moderate Wind Swing Condition, 9 psf assumed instead of minimum NESC 6 psf)

7.6 <u>Formulas for Insulator Swing</u>: The formulas in equations 7-1 and 7-2, can be used to determine the angle of insulator swing that will occur under a given set of conditions for either tangent or angle structures.

$$\tan\phi = \frac{(2)(T)(\sin\theta/2)+(HS)(p_c)}{(VS)(w_c)+(1/2)(W_i)} \qquad \text{Eq. 7-1}$$

$$p_c = \frac{(d_c)(F)}{12} \qquad \text{Eq. 7-2}$$

where:

$\emptyset$ = angle with the vertical through which the insulator string swings, in degrees
θ = line angle, in degrees
T = conductor tension, pounds
HS = horizontal span, feet
VS = vertical span, feet
p_c = wind load per unit length of bare conductor in pounds per foot
w_c = weight per unit length of bare conductor in pounds per foot
W_i = weight of insulator string (wind pressure neglected), in pounds. (See Appendix C for insulator string weights).
d_c = conductor diameter in inches
F = wind force in lbs/ft^2

In order for equation 7-1 to be used properly, the following sign conventions are to be followed:

Condition	Sign Assumed
• Wind - Blowing insulator toward structure	+
• "(2)(T)(sin θ/2)" term (force on insulator due to line angle):	
Pulling insulator toward structure	+
Pulling insulator away from structure	-
• Insulator swing angle	
Angle measured from a vertical line through point of insulator support in toward structure	+
Angle measured from a vertical line through point of insulator support away from structure	-

7.7 <u>Insulator Swing Charts</u>: Insulator swing charts similar to those in Figures 7-4 and 7-5 can be developed by using equation 7-3 and the maximum angle of insulator swing values as limited by clearance to structure.

$$VS = \frac{(2)(T)(\sin\theta/2)+(HS)(p_c)}{(w_c)(\tan\phi)} - \frac{W_i}{(2)(w_c)} \qquad \text{Eq. 7-3}$$

The symbols and sign conditions are the same as those provided for equation 7-1. Equation 7-3 is derived from equation 7-1 and solving for VS.

7.8 <u>Excessive Angles of Insulator Swing</u>: If upon spotting a line, calculations shown a structure will have excessive insulator swing, one or more of the measures outlined in Section 10.4 of Chapter 10 of this bulletin may be required to alleviate the problem.

7.9 Example: For the TH-10 tangent structure, develop the insulator swing chart. Assume that it is desired to turn slight angles with the tangent structure and the insulator string assembly uses the ball hook.

7.9.1 Given:

a. Voltage: 161 kV
Structure: TH-10
Conductor: 795 kcmil 26/7 ACSR
Insulation: Standard (10 bells)

b. NESC heavy loading district
High winds: 14 psf
Ruling Span: 800 ft.

c. Conductor Tensions

6 psf wind
0°F
6,244 lbs. initial tension

No wind
60°F
4,633 lbs. final tension

12.5 psf wind
32°F
10,400 lbs. final tension

7.9.2 Solution: Using the information on conductor sizes and weights, allowable swing angles, insulator string weights from the appendices of this bulletin and using equation 7-3, the following calculation tables and the swing chart in Figure 7-6 are created.

7.10 Example: On the plan and profile drawings, the engineering is checking insulator swing for the TH-10 structure in example 7-9. For a certain TH-10 structure with no line angle, the horizontal span is 800 feet. Determine the minimum vertical span.

7.10.1 Same Information as 7.9.1

7.10.2 Solution: From Figure 7-6, for a horizontal span of 800 feet, the vertical span must be greater than 241 feet (see also tables for Figure 7-6). Many programs which are used to develop plan-profile drawings will automatically check insulator swing or will use insulator swing as a parameter in the spotting of structures.

FIGURE 7-6: INSULATOR SWING CHART FOR EXAMPLE 7-9

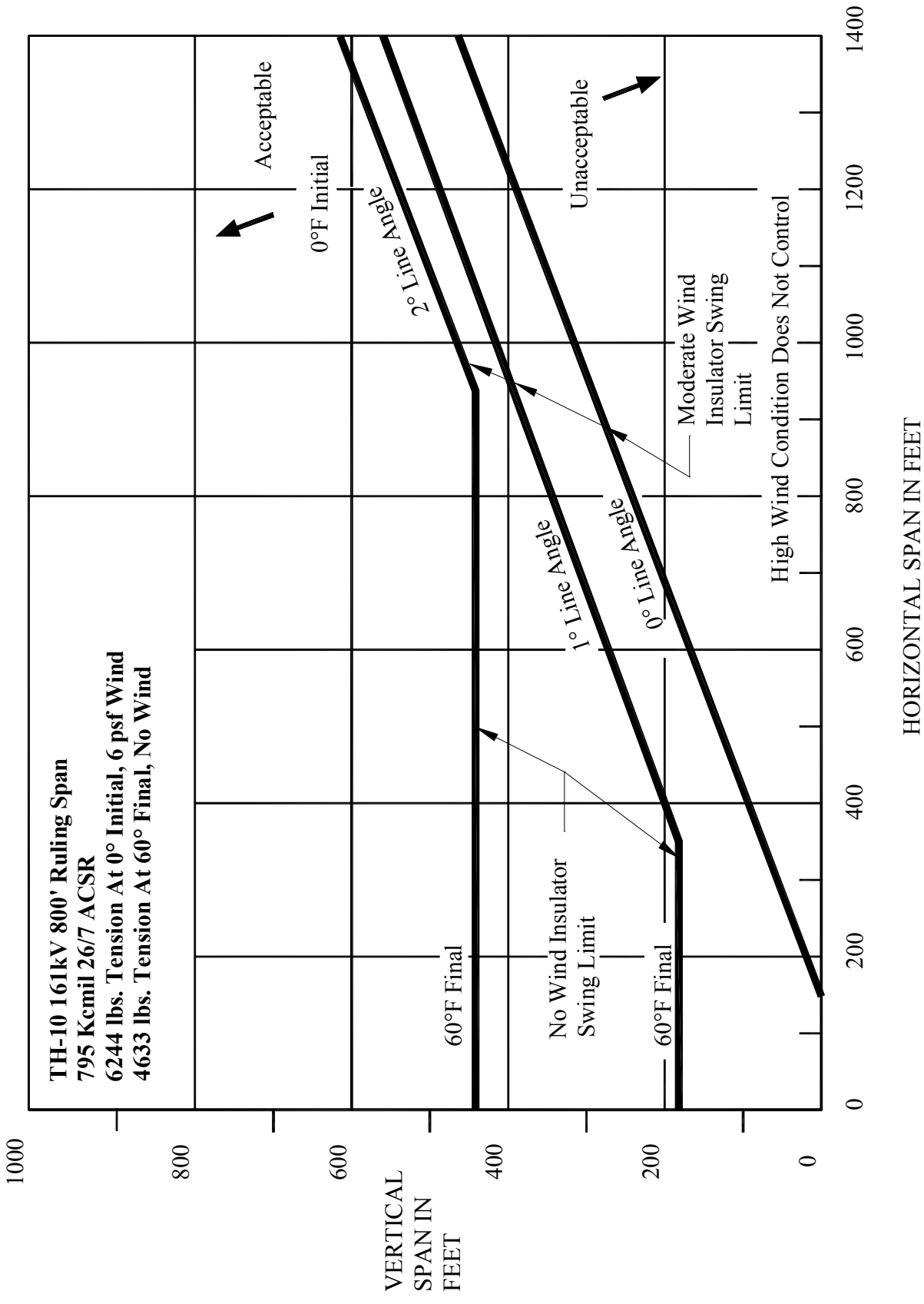


FIGURE 7-6 INSULATOR SWING CHART FOR EXAMPLE 7-9 (continued)

$$VS = \frac{(2)(T)(\sin\theta/2)+(HS)(p_c)}{(w_c)(\tan\phi)} - \frac{W_i}{(2)(w_c)}$$

Note: for the no wind case, vertical span is independent of horizontal span. It is only dependent upon line angle.

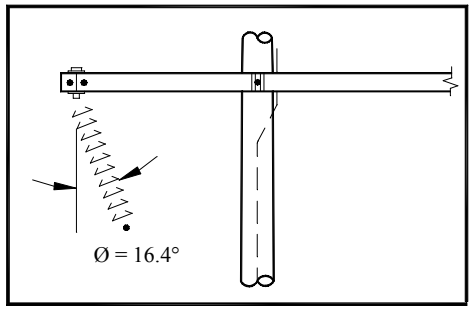
θ	**1°**	**2°**			
sin θ/2	.00872	.01745			
a) (2)(T)(sin θ/2)	80.26	161.71			
b) (HS)(p_c)	0	0			
a + b	80.26	161.71			
c) (w_c)(tan Ø)	.32	.32			
d) (a + b)/c	251.13	502.25			
e) W_i/(2)(w_c)	61.70	61.70			
d – e = VS	189.43	440.55			

θ					
sin θ/2					
a) (2)(T)(sin θ/2)					
b) (HS)(p_c)					
a + b					
c) (w_c)(tan Ø)					
d) (a + b)/c					
e) W_i/(2)(w_c)					
d – e = VS					

θ					
sin θ/2					
a) (2)(T)(sin θ/2)					
b) (HS)(p_c)					
a + b					
c) (w_c)(tan Ø)					
d) (a + b)/c					
e) W_i/(2)(w_c)					
d – e = VS					

Ø = angle with the vertical through which insulator string swings.

θ = line angle
T = conductor tension
HS = horizontal span
VS = vertical span
p_c = wind load on conductors
w_c = weight of conductor/ft.
W_i = weight of insulator string



Structure: TH-10
Conductor: 795 26/7 ACSR
Voltage: 161 kV
Insulator Swing Condition:

Ruling span 800 ft.
Loading district: Heavy
No of Insulators: 10
No wind
(F=0 lbs at 60°F)

Ø = 16.4°
p_c = 0 lbs./ft
w_c= 1.0940 lbs./ft
T= 4,633 lbs
W_i= 135 lbs

Conductor dia: 1.108

$$p_c = \frac{(d)(F)}{12}$$

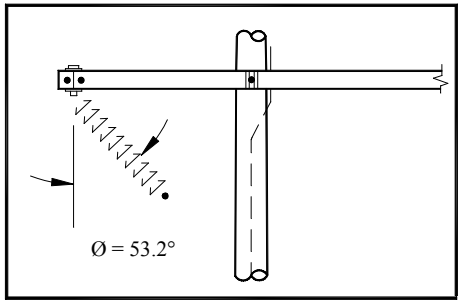
FIGURE 7-6: INSULATOR SWING CHART FOR EXAMPLE 7-9 (continued)

$$VS = \frac{(2)(T)(\sin\theta/2)+(HS)(p_c)}{(w_c)(\tan\phi)} - \frac{W_i}{(2)(w_c)}$$

θ = 0°	HS=200	HS=400	HS=800	HS=1000
sin θ/2	0	0	0	0
a) (2)(T)(sin θ/2)	0	0	0	0
b) (HS)(pc)	110.80	221.60	443.20	554.00
a + b	110.80	221.60	443.20	554.00
c) (wc)(tan Ø)	1.460	1.460	1.460	1.460
d) (a + b)/c	75.77	151.53	303.07	378.83
e) Wi/(2)(wc)	61.70	61.70	61.70	61.70
d – e = VS	14.07	89.83	241.37	317.13
θ = 1°	HS=200	HS=400	HS=800	HS=1000
sin θ/2	.008727	.008727	.008727	.008727
a) (2)(T)(sin θ/2)	1.08.98	108.98	108.98	108.98
b) (HS)(pc)	110.80	221.60	443.20	554.00
a + b	219.78	330.58	552.18	662.98
c) (wc)(tan Ø)	1.460	1.460	1.460	1.460
d) (a + b)/c	150.29	226.05	377.59	453.35
e) Wi/(2)(wc)	61.70	61.70	61.70	61.70
d – e = VS	88.59	164.35	315.89	391.65
θ = 2°	HS=200	HS=400	HS=800	HS=1000
sin θ/2	.017452	.017452	.017452	.017452
a) (2)(T)(sin θ/2)	217.95	217.95	217.95	217.95
b) (HS)(pc)	110.80	221.60	443.20	554.00
a + b	328.75	439.55	661.15	771.95
c) (wc)(tan Ø)	1.460	1.460	1.460	1.460
d) (a + b)/c	224.80	300.57	452.10	527.87
e) Wi/(2)(wc)	61.70	61.70	61.70	61.70
d – e = VS	163.10	238.87	390.40	466.17

Ø = angle with the vertical through which insulator string swings.

θ = line angle
T = conductor tension
HS = horizontal span
VS = vertical span
p_c = wind load on conductors
w_c = weight of conductor/ft.
W_i = weight of insulator string



Structure: TH-10 Ruling span 800 ft.

Conductor: 795 26/7 ACSR Loading district: Heavy

Voltage: 161 kV No of Insulators: 10

Insulator Swing Condition: **Moderate wind (F=6 psf at 0°F)**

Ø = 53.2°
p_c = 0.554 lbs./ft
w_c = 1.0940 lbs./ft
T = 6,244 lbs
W_i = 135 lbs

Conductor dia: 1.108

$$p_c = \frac{(d)(F)}{12}$$

FIGURE 7-6: INSULATOR SWING CHART FOR EXAMPLE 7-9 (continued)

$$VS = \frac{(2)(T)(\sin\theta/2)+(HS)(p_c)}{(w_c)(\tan\phi)} - \frac{W_i}{(2)(w_c)}$$

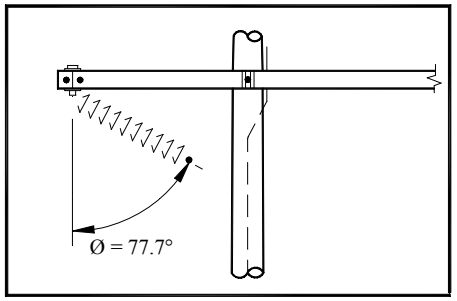
θ = 0°	**HS=200**	**HS=400**	**HS=800**	**HS=1000**
sin θ/2	0	0	0	0
a) (2)(T)(sin θ/2)	0	0	0	0
b) (HS)(p_c)	230.80	461.60	923.20	1154.00
a + b	230.80	461.60	923.20	1154.00
c) (w_c)(tan Ø)	5.02	5.02	5.02	5.02
d) (a + b)/c	46.00	92.00	183.99	229.99
e) W_i/(2)(w_c)	61.70	61.70	61.70	61.70
d – e = VS	-15.70	30.30	122.29	168.29

θ = 1°	**HS=200**	**HS=400**	**HS=800**	**HS=1000**
sin θ/2	.008727	.008727	.008727	.008727
a) (2)(T)(sin θ/2)	181.51	181.51	181.51	181.51
b) (HS)(p_c)	230.80	461.60	923.20	1154.00
a + b	412.31	643.11	1104.71	1335.51
c) (w_c)(tan Ø)	5.02	5.02	5.02	5.02
d) (a + b)/c	82.17	128.17	220.17	266.17
e) W_i/(2)(w_c)	61.70	61.70	61.70	61.70
d – e = VS	20.47	66.47	158.47	204.47

θ = 2°	**HS=200**	**HS=400**	**HS=800**	**HS=1000**
sin θ/2	.017452	.017452	.017452	.017452
a) (2)(T)(sin θ/2)	363.01	363.01	363.01	363.01
b) (HS)(p_c)	230.80	461.60	923.01	1154.00
a + b	593.81	824.61	1286.21	1517.01
c) (w_c)(tan Ø)	5.02	5.02	5.02	5.02
d) (a + b)/c	118.35	164.35	256.34	302.34
e) W_i/(2)(w_c)	61.70	61.70	61.70	61.70
d – e = VS	56.65	102.65	194.64	240.64

Ø = angle with the vertical through which insulator string swings.

θ = line angle
T = conductor tension
HS = horizontal span
VS = vertical span
p_c = wind load on conductors
w_c = weight of conductor/ft.
W_i = weight of insulator string



Structure: TH-10 Ruling span 800 ft.

Conductor: 795 26/7 ACSR Loading district: Heavy

Voltage: 161 kV No of Insulators: 10

Insulator Swing Condition: **High wind (F=12.5 psf at 32°F)**

Ø = 77.7°
p_c = 1.154 lbs./ft
w_c = 1.0940 lbs./ft
T = 10,400 lbs
W_i = 135 lbs

Conductor dia: 1.108

$$p_c = \frac{(d)(F)}{12}$$

8. INSULATION AND INSULATORS

8.1 Insulator Types: Insulation is defined as the separation between conducting surfaces by means of a non-conducting (dielectric) material that would economically offer a high resistance to current. Insulators may be fabricated from porcelain, toughened glass, fiberglass rods and sheds of polymer or silicone construction.

The main types of insulators used on transmission lines are suspension insulators using bells or polymer strings, pin insulators, and vertical and horizontal posts. Several suspension bell units are connected in a string to achieve the insulation level desired. The polymer suspension is one unit with an insulation level determined largely by its length. Horizontal post units are made of porcelain or polymer and are single units with a desired rating. See Figures 8-1 and 8-2.

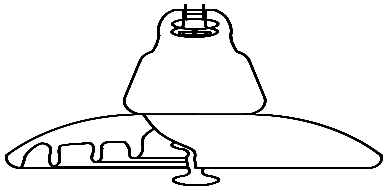


FIGURE 8-1: A STANDARD PORCELAIN SUSPENSION BELL

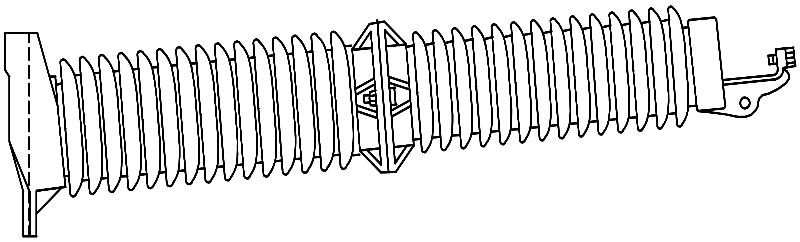


FIGURE 8-2: A TYPICAL PORCELAIN HORIZONTAL POST INSULATOR

8.2 Insulator Materials

8.2.1 Porcelain insulators have been the industry standard as specified by ANSI requirements for electrical and mechanical capacities. Although porcelain insulators have a history of long, useful lives, the strings are heavy and subject to breakage from gunshots. The connecting portions of porcelain insulators are metal components which are embedded in high strength cement as specified by ANSI standards. Strength ratings for porcelain insulators are verified by proof loading requirements of each manufactured unit, and stamped accordingly.

8.2.2 Toughened glass insulators are similar in construction to the porcelain insulator. They are heavy, and are also subject to vandalism exposure. ANSI fabrication standards are also available for toughened glass.

8.2.3 Non-ceramic (polymer) insulators typically consist of a fiberglass rod that is sheathed with weathershed 'bells' made of either rubber-based or silicone-based polymers. The connecting ends are typically compressed metal fittings. ANSI standards have been developed for suspension units.

Non-ceramic assemblies offer varieties of end fittings, lengths and strength capacities. They are much lighter in weight than their porcelain and glass counterparts. Polymers may be subject to damage by corona voltage, ultraviolet radiation, or physical deterioration which may not be apparent. Deterioration of a fiberglass rod may result in a reduction in strength of the unit.

8.3 Insulation Levels Using Suspension Bells: Table 8-1 provides suggested insulation levels. However, circumstances such as high altitude, contamination, high isokeraunic levels, or high footing resistance, may warrant additional insulation. If wood structures with steel arms, steel structures, or concrete pole structures are used in areas where there is a high isokeraunic level, consideration should be given to using one additional suspension bell beyond the standard agency recommended insulation levels.

8.3.1 Tangent and Small Angles: Table 8-1 indicates the recommended number of 5-3/4 x 10 in. suspension insulators to be used per phase on wood tangent and small angle structures. Also given are the electrical characteristics of the insulator strings.

8.3.2 Angles: For angle structures where the conductor tension is depended upon to pull the insulator string away from the structure, one more insulator bell should be added to the number of bells recommended for tangent structures. The sole exception to this is 34.5 kV where no additional bells are needed.

TABLE 8-1
RECOMMENDED ISULATION LEVELS*AT SEA LEVEL
(SUSPENSION AT TANGENT AND SMALL ANGLE STRUCTURES)
Flashover Characteristics in kV

Nominal L-L Voltage in kV	No. of 5-3/4x10" Bells	60 Hz Low Freq Dry*	60 Hz Low Freq Wet	Impulse Positive	Impulse Negative	Total Leakage Distance inches
34.5	3	215	130	355	340	34.5
46	3	215	130	355	340	34.5
69	4	270	170	440	415	46
115	7	435	295	695	670	80.5
138	8	485	335	780	760	92
161	10	590	415	945	930	115
230	12	690	490	1105	1105	138

**See NESC Rule 273, Table 273-1 for minimum insulation level requirements*

8.3.3 Deadends: In situations where the insulator string is in line with the conductor, the number of bells should be two more than is used for tangent structures. These situations occur at large angles, and tangent deadends where the conductor is deadended onto an insulator string. The sole exception to this is 34.5 kV where one additional bell is used.

8.4 Insulation Levels Using Post Insulators: Agency recommended electrical characteristics for horizontal post insulators are given in Table 8-2.

TABLE 8-2
RECOMMENDED INSULATION LEVELS AT SEA LEVEL
(POSTS AT TANGENT AND SMALL ANGLE STRUCTURES)
Flashover Characteristics in kV

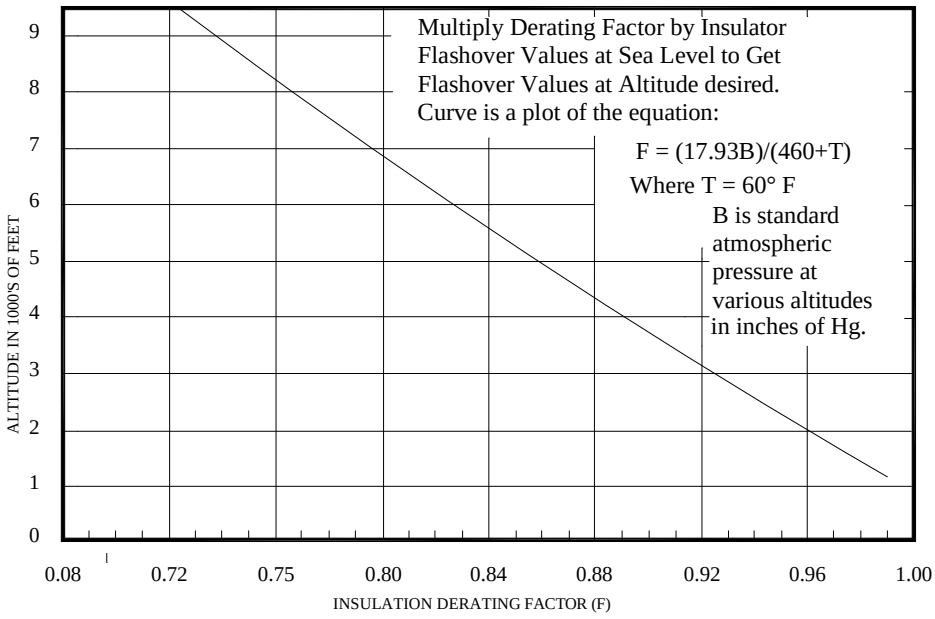
Nominal L-L Voltage in kV	*60 Hz Low Freq Dry*	*60 Hz Low Freq Wet*	*Impulse*		*Total Leakage Distance inches*
			Positive	*Negative*	
34.5	125	115	210	260	29
46	150	135	255	344	40
69	200	180	330	425	53
115	380	330	610	780	100
138	430	390	690	870	110

8.5 Electrical Characteristics of Insulators: Because low frequency dry flashover ratings can be tested easily and accurately, these ratings are generally the most common flashover values referred to when comparing insulators. However, flashover (60 Hz) of an insulator in service almost never occurs under normal dry operating conditions, so these ratings are probably the least significant of insulator electrical characteristics. When comparing different types of insulators (e.g., post vs. suspension) characteristics such as impulse and wet flashover do not necessarily follow the same pattern as the low frequency dry flashover ratings. For these reasons, Tables 8-1 and 8-2 are developed and provide both impulse and wet flashover values. For voltages up to 230 kV the most severe stress on the insulation is usually caused by lightning, and the most important flashover characteristic is the impulse flashover values.

8.6 High Altitude Considerations

8.6.1 General: As altitude increases, the insulation value of air decreases and an insulator at a high elevation will flash over at a lower voltage than the same insulator at sea level. Figure 8-3 gives the derating factors for insulator flashover values as a function of altitude. These derating factors apply to both low frequency flashover values and impulse flashover values.

FIGURE 8-3: INSULATION DERATING FACTOR vs. ALTITUDE
IN 1,000's OF FEET (230 kV and below)



In addition to increasing the number of insulators for high altitude, it is also necessary to increase the structure air gap clearances. This could result in a decreased allowable insulator swing angle or a longer crossarm (see Chapter 7 for details).

8.6.2 Example of Insulation Needed at High Altitudes: A line is located at 6000 feet elevation. The derating factor (from Figure 8-3) is .827. At 138 kV, using the sea-level requirement for low frequency dry flashover of 435 kV from Table 8-1, the line would require 526 kV (435/.827) at 6000 feet. A 10 bell string should be used instead of 7 bells. The clearance to structure and clearance to guy wire should be increased (see Table 7-1 for guidance).

8.6.3 Insulation for Lines with Relatively Small Changes in Altitude: When the insulation derating factor for the line altitude is at a value less than approximately 90 percent of the insulation value at sea level (see Figure 8-3), then additional insulation should be added to bring the insulation level up to at least 90 percent of the sea level value.

8.6.4 Insulation for Lines with Significant Elevation Changes but Less than 5000 Feet: If the elevation change in a line from its low point to its highest point is less than 5000 feet, it is recommended that insulation for the entire length of the line be based on the weighted average altitude of the line. This can be achieved by applying the procedure given in paragraph 8.6.2 to that weighted average altitude.

8.6.5 Insulation for Line with Elevation Changes Greater than 5000 Feet: Where the elevation change is greater than 5000 feet, the following two steps should be taken:

a. The entire line insulation should be upgraded for the minimum altitude of the line using the procedure in paragraph 8.6.2 above.

b. Additional insulation should be added in sections of line where it is needed. This need arises where the altitude of the line increases to the point where the insulation value is less than approximately 90 percent of the insulation value at the minimum line altitude. This means there may be different numbers of insulator bells at different points along the same line.

8.6.6 Example of Additional Insulation for High Altitudes and Line Elevation Changes Less than 5000 feet: A 161 kV line is to be built in an area where altitude ranges from 5430 ft. to 7580 ft. Determine how much additional insulation, if any, is necessary.

Solution: The elevation change for the line from its lowest point to its highest point is less than 5000 ft. Therefore, the insulation should be based on the weighted average altitude. Since we do not know the distribution of the line at the various altitudes, we will assume a uniform distribution. Thus:

$$\text{Average altitude} = \frac{5430 + 7580}{2} = 6505 \text{ ft.}$$

From Figure 8-3 the derating factor for an average altitude of 6505 ft is 0.81. Since paragraph 8.6.2 indicates that additional insulation is needed if the derating factor is less than 0.90, additional insulation will be needed.

According to paragraph 8.6.5, the insulation value should be brought up to approximately 90 percent of the sea level value, which for 161 kV is:

(0.9)(590) kV) = 531 kV

(590 kV is the low frequency dry flashover value of 10 bells at sea level).

The 531 kV requirement for low frequency dry flashover at sea level needs to be increased to account for the higher elevation. Applying the derating factor to the 531 kV, the low frequency dry flashover value of the string needs to be:

531/.81 = 655 kV

From Appendix C, the low frequency dry flashover of 11 bells is 640 kV. For 12 bells it is 690 kV. Therefore, the addition of one extra bell will not quite bring the insulation level up to the 90 percent of sea level. The above calculations seem to indicate the need to add two extra bells. However, some judgment should be exercised as to whether the second additional bell is used. Even though one bell extra does not quite provide enough additional insulation, it comes close. If the expected frequency and severity of lightning storms is not particularly high, one extra bell might be sufficient. Depending on experience and judgement, at least one and possibly two extra bells should be used.

8.7 Lightning Considerations

8.7.1 General: Transmission lines are subjected to three types of voltage stress that may cause flashover of the insulation: power frequency voltage, switching surges and lightning surges. Flashovers due to power frequency voltages are primarily a problem in contaminated conditions and are discussed in section 8.8. Of the remaining two causes of flashovers, lightning is the more severe for lines of 230 kV and below.

8.7.2 Lightning Flashover Mechanism: When lightning strikes a transmission line, it may hit either the overhead ground wire or a phase conductor. If a phase conductor is hit, there will almost certainly be a flashover of the insulation. To minimize this near certainty of a flashover, an overhead ground wire is used to intercept the lightning strokes. To reduce the possibility of a shielding failure, the shielding angle should be kept at 30° or less. (The shielding angle is the angle measured from the vertical between the OHGW and the phase conductors, as shown in Figure 8-4). On H-frame structures where two overhead ground wires are used, the center phase may be considered to be properly shielded even if the shielding angle to it is greater than 30°. For structures whose height is in excess of 92 feet, shielding angles of less than 30° as indicated in Table 8-3, should be used. Where there is an unusually high exposure to lightning, such as at river crossings, an even smaller shielding angle may be warranted.

TABLE 8-3
REDUCED SHIELDING ANGLE VALUES

Structure Height, feet	Recommended Shielding Angle, degrees
92	30
99	26
116	21

If lightning strikes an overhead ground wire, a traveling current wave will be set up which will induce a traveling voltage wave. This voltage wave will generally increase in magnitude as it travels down the wire, until it reaches a structure where the reflection of the traveling wave from the ground prevents the voltage from further increasing. (The overhead ground wire is grounded at every structure). If the traveling voltage wave at the structure is sufficiently high, a "back flashover" across the insulation from the structure ground wire or from the overhead ground wire to the phase conductor will occur. The factors that determine if a back flashover will occur are: the amount of insulation, the footing resistance (the higher the footing resistance, the higher the voltage rise at the structure) and the span length.

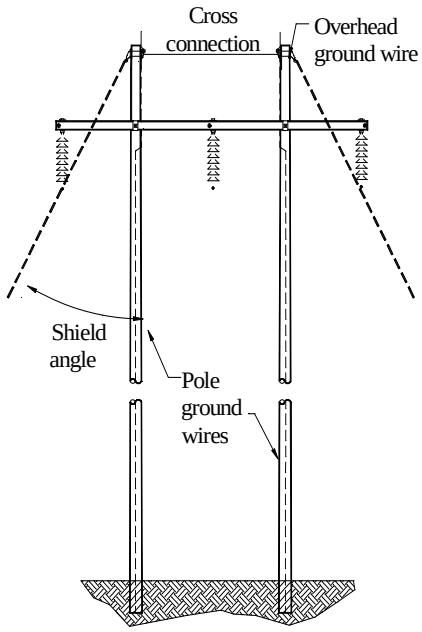


FIGURE 8-4: SHIELDING ANGLE, POLE AND OVERHEAD GROUND WIRES

8.7.3 <u>Designing for Lightning</u>: An overhead ground wire should be used in all locations where the isokeraunic level is above 20. The overhead ground wire should be grounded at every structure by way of a structure ground wire. At H-frame structures, the OHGW's should each be connected to a structure ground wire and to one another so that if one structure ground wire breaks, both overhead ground wires will still be grounded.

In areas where the isokeraunic level is 20 or less, an overhead ground wire should still be used for a distance of 1/2 mile from a substation. A map of isokeraunic levels is given in Appendix E.

8.7.4 <u>Footing Resistance</u>: For satisfactory lightning performance of a line, low footing resistance is essential. Exactly what value of footing resistance is acceptable or unacceptable is not a simple matter as it depends upon several variables. Previous successful experience with a similar line in similar circumstances can be one guide. The following references may be useful in determining what lightning outage rate a given footing resistance would yield.

(a) "Transmission Line Reference Book, 115 kV and Below," Palo Alto, Calif., Electric Power Research Institute, 1975.

(b) "Estimating Lightning Performance of Transmission Lines," J. M. Clayton and F. S. Young. <u>IEEE Transactions on Power Apparatus and Systems</u>, November 1964, pp. 1102-1110.

A grounded structure has a good chance to withstand a lightning flashover provided that conductor insulation and ground resistance have been properly analyzed and coordinated.

A lightning outage rate of 1 to 4 per 100 miles per year is acceptable with the lower number more appropriate for lines in the 161 to 230 kV range.

Generally, experience has shown that the footing resistance of individual structures of the line especially within 1/2 mile of the substation should be less than 25 ohms in high isokeraunic areas.

When a line is being built, it is recommended that the footing resistance of the ground connection be measured and recorded on a spot check basis. If footing resistance problems are expected, more frequent measurements should be made and recorded. If experience indicates that the lightning outage rate is not acceptable, these measurements readings can be useful when taking remedial measures.

Footing resistance should not be measured immediately after a rain when the soil is moist. If the footing resistance is higher than desired, additional driven rods may be used to reduce it. If the earth's resistivity is very high, counterpoise rather than driven rods may be required. Reference (b) this section gives guidance in the selection of counterpoise.

8.7.5 Lightning Arresters: In areas where structure grounding is difficult to achieve, or the lightning performance of an existing transmission line needs to be improved, Metal Oxide Varistor (MOV) line arresters can be installed. These arresters should be coordinated with the substation station class arresters for proper performance. The engineer should determine the size of the substation arresters and choose a slightly higher Maximum Continuous Over Voltage (MCOV) rating on the transmission line to prevent the line arresters from taking all of the flashover duty.

On a triangular three wire designs, adding an arrester to the top phase of every structure will typically give some shield angle protection to the other phases. For best performance, the arrester should be tied to a ground system with 10 ohms or less of resistance. If good grounding is not available, the borrower should consider adding lightning arresters to all three phases. Lightning arresters can also be installed on shielded lines to minimize back flashover where good grounding is difficult. The engineer should design for phase-to-phase clearances between the failed arrester, open position, and other phase wires since the arrester may drop near the other energized phase position.

8.8 Contamination Considerations: The problem of contamination induced flashovers should be considered if a line is to be built near a seacoast, an industrial district, or at other locales where airborne contaminants may accumulate on insulators.

8.8.1 Contamination Flashover Mechanism: When a layer of contaminants on an insulator is moistened by fog, dew, light rain or snow, it will become more conductive and the leakage current along the surface of the insulator will greatly increase. Where the current density is the greatest (for suspension insulators near the pin, and for post insulators at the points of least diameter), heat caused by the increased leakage current will evaporate the moisture causing the formation of a dry band. This band usually has an higher resistance than the adjacent moistened area which means that the band will support almost all the voltage across it. This will result in the breakdown of the air and the formation of an arc across the dry band. The arc will cause the moisture film at the dry band edges to dry out, enlarging the dry band, eventually to the point where the voltage across the band is just below the air breakdown value. If an increase in precipitation occurs causing a lowering of contaminant resistance, a second breakdown can occur. If conditions are right, a cycle of repeated and ever-increasing surges will be set up which

will result in several discharges joining, elongating and bridging the entire insulator and resulting in a power arc. See Figure 8-5 for a graphic description.

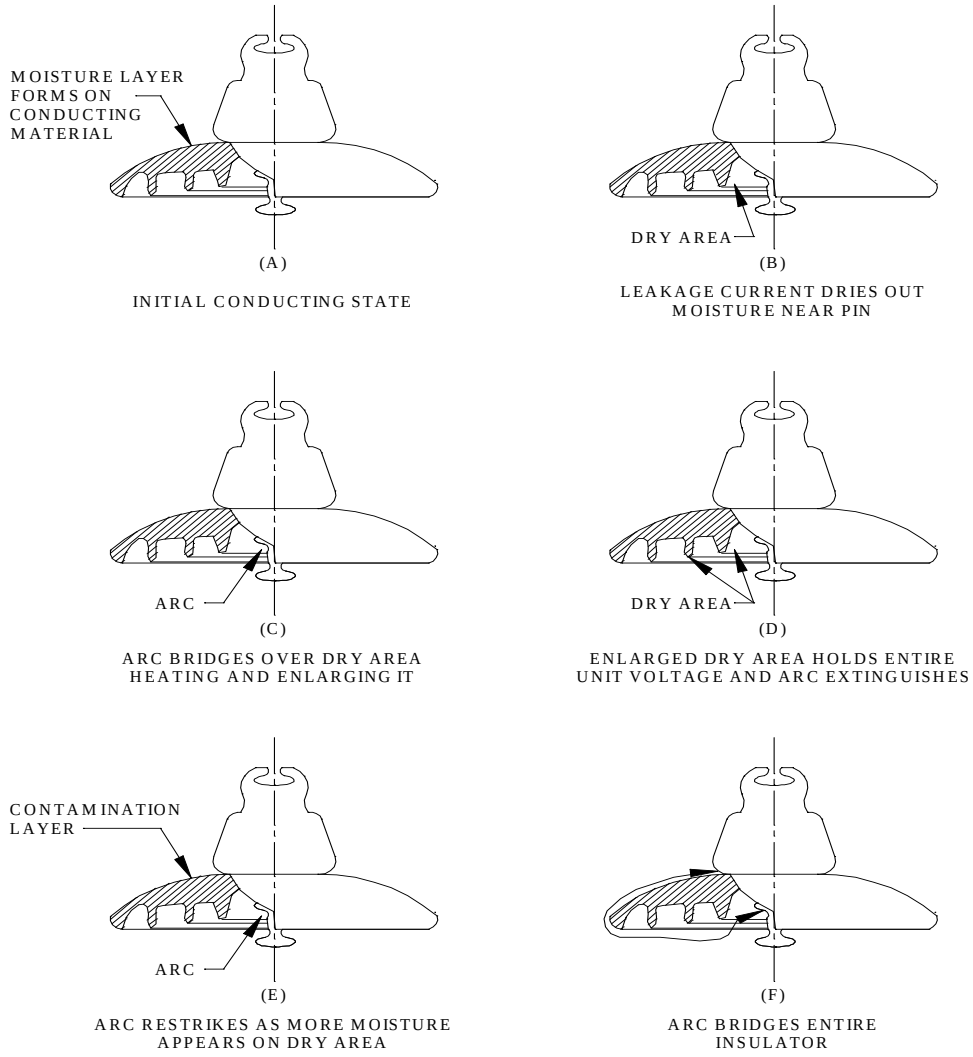


FIGURE 8-5: CONTAMINATION BREAKDOWN PROCESS
OF A SINGLE PORCELAIN INSULATOR UNIT

8.8.2 <u>Effect of Insulator Orientation</u>: The orientation of insulators has an effect on contamination performance. Vertical strings of suspension insulators or vertical post insulators do not wash well in the rain because of the sheltering effects of the insulator skirts. Contaminants will tend to remain on the underside of the insulator which is not immune from the moistening effects of fog or wind blown rain and snow. Horizontally oriented suspension insulators and post insulators have their undersides more thoroughly washed by the rain and therefore tend to fare better than vertical insulators in contaminated areas. Another advantage of insulators in nonvertical positions is that any ionized gases caused by arcing will not contribute to setting up conditions where an arc could jump from one bell to another or along the skirts of a vertical post.

8.8.3 Designing for Adverse Contamination Conditions: There are several means available for improving line insulation performance in a contaminated atmosphere.

One way to compensate for contaminated conditions is to increase the leakage distance of the insulation. The leakage distance is the distance along the surface of the insulators from the top of the string (or post) to the energized hardware, not including any metal such as insulator caps and pins.

Table 8-4 gives recommended leakage distances for various levels of contamination. The increased leakage distance can be obtained by adding additional standard insulator bells (using a longer post insulator) or by using fog insulators, which have more leakage distance for the same overall insulator length. The additional leakage distance on fog insulators is obtained by having more and/or deeper skirts on the underside of the insulator bell. In addition to the leakage distance, the shape of the insulator has an effect on contamination performance, especially when fog units are being used.

Research into the performance of existing lines with similar contamination should play an important part in the final determination of insulating for atmospheric contamination.

An alternative to increasing the total leakage distance of the insulator string is to use a resistance graded insulators. These insulators have a glaze that permits a small but steady leakage current to flow over their surface. This leakage current gives the insulator much better contamination performance without having to increase leakage distance. The base of a resistance graded insulator should be solidly bonded to the structure ground wire to permit the leakage current to flow easily to the ground. To aid in determining whether to use this type of insulator, its advantages and disadvantages are listed below.

Advantages and Disadvantages of Resistance Graded Insulators

Advantages	Disadvantages
• No extra leakage distance required.	• Higher initial costs.
• Longer intervals between insulator washings.	• Small but continuous power loss.
• No radio noise (due to a more uniform voltage distribution across string).	• Not entirely successful in very heavily contaminated areas.

TABLE 8-4
SUGGESTED LEAKAGE DISTANCES FOR CONTAMINATED AREAS

Contaminate Level	Environment	Equivalent Amount NaCl mg/cm^2	Suggested Leakage Distance rms L-G* in/kV
Very Light	Areas without industries and with low density of houses equipped with heating plants. Areas with some density of industries or houses but subject to frequent winds and/or rainfall. Areas not exposed to sea winds.	0-.03	NA-1.0
Light	Areas with industries not producing particularly polluting smoke and/or areas with average density of houses equipped with heating plants. Areas with high density of houses and/or rainfall. Areas exposed to winds from the sea but not less than 10 miles from the coast	.03-.06	1.0-1.25
Moderate	Areas with high density of industries and suburbs of large cities with high density of heating plants producing pollution. Areas close to the sea or in any case exposed to relatively strong winds from the sea (within 10 miles of the sea).	.06-.1	1.5-1.75
Heavy	Areas subjected to industrial smoke producing particularly thick conductive deposits. Areas with very strong and polluting winds from the sea. Desert areas, characterized by no rain for long periods, exposed to strong winds carrying sand and salt, and subjected to regular condensation	.1-.25	2.0-2.5

*rms L-G is root mean square line to ground voltage

Washing of the insulators should not be used in place of properly designing for contamination but rather should be used in addition to the other steps where it is felt to be necessary.

Insulator performance in a contaminated environment can be improved by coating the surface with suitable silicone grease. The grease absorbs the contamination and repels water. It is necessary, however, to remove and replace the grease at intervals determined by the degree of contamination. As with washing, the use of grease should only be considered as a remedial step. Resistance graded insulators should not be greased.

8.9 Mechanical Considerations (Porcelain and Non-ceramic)

8.9.1 Suspension Insulators: Strength rating methods and nomenclature vary depending on the insulator material.

For porcelain, ANSI C29.1 specifies Mechanical and Electrical (M&E) procedures. The M&E value is determined by a combined mechanical and electrical test. The insulator has a voltage (75 percent of its rated dry flashover) impressed across it while a mechanical load is gradually applied to the insulator. For non-ceramics, most manufacturers conduct specified mechanical loading (SML) procedures to determine a polymer insulator's failure rating. These procedures are similar to the M&E for porcelain, but no electrical test is applied.

ANSI C 29.2 defines standard mechanical ratings for porcelain as: 15,000 lbs., 25,000 lbs., 36,000 lbs. and 50,000 lbs. ANSI C29.12 defines standard SML's for non-ceramic transmission insulators as: 20,000 lbs., 25,000 lbs., 36,000 lbs. and 40,000 lbs.

For recommended insulator loading limits, refer to Table 8-5. Under NESC district loading conditions, suspension insulators should not be loaded to more than 40 percent of their standard ANSI M&E rating for porcelain insulators or 40 percent of their ANSI SML for non-ceramics. If a heavier loading than the NESC district loading can be expected to occur with reasonable regularity, then the 40 percent loading limit should be maintained at the higher loading limit.

Under extreme ice or high wind (50-year mean recurrence interval wind conditions) the load on the insulator should not exceed 65 percent of the M&E strength of the insulator for porcelain and 50 percent of the M&E strength for non-ceramics.

Generally, porcelain insulators with a 15,000 pound M&E rating will be satisfactory for tangent structures. However, stronger insulators may be needed on long spans with large conductors and at deadends and angles where the insulators carry the resultant conductor tension.

TABLE 8-5
SUMMARY OF RECOMMENDED INSULATOR LOADING LIMITS

Insulator Type	NESC District Loading	Extreme Loading	
		Non-ceramic	Porcelain
Suspension	40% (% of ANSI standard SML or M&E strength)	50% (% of ANSI standard SML strength)	65% (% of ANSI standard M&E strength)
Horizontal Post Cantilever Tension, Compression	 40% 50% (% of appropriate rated ultimate strength value)	 50% 50% (% of appropriate rated ultimate strength value)	 65% 65% (% of appropriate rated ultimate strength value)
Vertical Post (Porcelain)	750 lbs.		-----
Vertical Pin Insulator (Porcelain, Mounted on the Crossarm)	500 lbs.		-----

When suspension non-ceramic insulators are used, the designer must be aware of the effects on insulator swing calculations due to increased length and reduced weight. Agency Bulletin 1724E-220, "Procurement and Application Guide for Non-Ceramic Composite Insulators," provides additional information on non-ceramic insulators. When used as a jumper, polymer suspension insulators may be pulled towards the structure because of their lightweight.

8.9.2 Horizontal Post Insulators (Porcelain and Non-ceramic): Under NESC loading district conditions, horizontal post insulators must not be loaded to more than 40 percent of their ultimate cantilever strength. As with suspension insulators, if a loading more severe than the NESC loading can be expected to occur with reasonable regularity, then the limit recommended for the more severe loading should be used. Under extreme ice conditions, the cantilever load on horizontal post insulators should not exceed 65 percent of the ultimate strength for porcelain and 50 percent of the ultimate strength for non-ceramics.

When a line angle is turned at a horizontal post structure, some or all of the insulators will be in tension. Under standard NESC loading conditions, the tension or compression load on the insulator must not exceed 50 percent of the ultimate tension or compression strength of the insulator. Under extreme loading conditions, the tension load on the insulator must not exceed 65 percent of the ultimate tension strength for porcelain and 50 percent of the ultimate tension strength of non-ceramic insulators.

Line post insulators are actually subjected to vertical, transverse and longitudinal loads simultaneously. These loads represent the actual applied stresses to the line post insulator core that are experienced in the field. Vertical, transverse and longitudinal loads each contribute to the total bending moment, or total stress on the rod. Non-ceramic manufacturers provide combined loading application curves, which represent the mechanical strength limits of a non-ceramic line post insulator when subjected to simultaneous loads. These curves are used to determine how the insulator's combined loading requirements compare with its cantilever (bending) strength. The combined loading application curves are used during the engineering stage to evaluate the mechanical strength of the insulator for specific line loading criteria.

There are three **special considerations** that must be mentioned in relation to horizontal post insulators:

Insulator Grounding: Where the structure ground wire passes near horizontal post insulators, it either should be stood off from the pole by means of a non-conducting strut **or** must be solidly bonded to the base of the insulator. This grounding is necessary to avoid radio noise problems.

Mechanical Impact Failures**:** Porcelain post insulators mounted on steel, concrete, or (in some cases) on wood structures using H-class poles, have experienced cascading mechanical failures due to impact loads because of the relative rigidity of the structures. To minimize the affects of impact loads, it is recommended that on rigid structures, non-ceramic insulators be used, **or** that porcelain post insulators be equipped with deformable bases, shear pin devices, or other means of relieving mechanical overloads.

Live Line Maintenance Issues: Many compact designs restrict the lineman for working on transmission lines while energized. Rule 441 of the NESC provides Table 441-1 which gives the recommended AC live work minimum approach distance for various voltages.

8.9.3 Porcelain Vertical Post and Pin Insulators Mounted on Crossarms: The maximum transverse load should be limited to 500 lbs. for standard single pin type agency standard structures and 750 lbs for standard vertical post type structures. The 500 lb. limit applies whether the load is from standard NESC loading district loadings alone or from a combination of loading district loading

and the resultant of conductor tension on line angles. These limit will prevent excessive stress on the insulator, the tie wires (if used), insulator pin (if used), and the wood crossarm. The transverse load can be doubled by using double pin or post construction. See Table 8-5 for a summary of recommended insulator loading limits.

8.9.4 Coordination of Insulator Strength with Strength of Associated Hardware: Care should be taken to coordinate the strength of the hardware associated with the insulator with the strength of the insulator itself.

8.9.5 Example of Maximum Vertical Span Due to Horizontal Post Insulator Strength: A 115 kV line is to be built using horizontal post insulators with a cantilever strength of 2,800 lbs. The conductor to be used is 477 kcmil 26/7 ACSR. Determine the maximum vertical span under:

1. Heavy loading district conditions; and
2. Under an extreme ice load, no wind, and 1.5 in. of radial ice

(See Chapter 11 for definitions of heavy loading and Chapter 9 for information on conductors).

Solution: From Appendix B, Conductors, the weights per unit length for the two conditions of the conductor are:

Heavy Loading District of 1/2 inch radial ice = 1.5014 lbs./ft.
Extreme radial ice of 1.5 inch =5.0554 lbs./ft.

Span Limits for Heavy Loading District:

$$\frac{2800 \text{ lbs.}(0.40)}{1.5014 \text{ lbs./ft.}} = 746 \text{ ft.}$$

Span Limits for Extreme Ice Condition:

$$\frac{2800 \text{ lbs.}(0.65)}{5.0554 \text{ lbs./ft.}} = 360 \text{ ft.}$$

The maximum vertical span is therefore 360 ft.

8.9.6 Example of Determining Minimum Suspension Insulator M&E Rating: A conductor has a maximum tension under heavy loading district conditions of 10,000 1bs. Under extreme radial ice of 1.5 in, it has a maximum tension of 16,000 lbs. Determine the minimum M&E rating of suspension bell insulators to be used in tension strings. (Tension strings are those insulator strings that are in line with the conductor and bear its full tension).

Solution:

Under NESC loading district conditions, the insulator can be loaded up to 40 percent of its M&E rating. Therefore:

(M&E rating)(0.4) = load
M&E rating = load/(0.4)
M&E rating = 10000 lbs./(0.4) = 25000 lbs.

Under extreme ice conditions the insulator can be loaded to 50 percent of its M&E rating. Therefore:

(M&E rating)(.65) = load
M&E rating = load/(0.65)
M&E rating = 16,000 lbs./(0.65) = 24,615 lbs.

c. Based on ANSI standard M&E ratings, the insulators to be used should have a minimum standard rating of 25,000 lbs.

9. CONDUCTORS AND OVERHEAD GROUND WIRES

9.1 Introduction: Of all the components that go into making up a transmission system, nothing is more important than the conductors. There are a surprising number of variables and factors that are to be considered when dealing with conductors. These include:

- Conductor type
- Conductor size
- Conductor ampacity
- Conductor thermal capacity
- Conductor tensions
- Corrosive atmosphere considerations
- Radio noise
- Conductor motion considerations
- Economic considerations

9.2 Types of Conductors: Of the currently available types of conductors, some are used much more extensively than others. Sections 9.2.1 through 9.2.11 provide descriptions of many of the conductor types.

9.2.1 ACSR (Aluminum Conductor Steel-Reinforced): ACSR is the most common type of conductor used today. It is composed of one or more layers of hard-drawn concentrically-stranded 1350 aluminum wire with a high-strength galvanized steel core. The core may be a single wire or stranded depending on the size. Because numerous stranding combinations of aluminum and steel wires may be used, it is possible to vary the proportions of aluminum and steel to obtain a wide range of current carrying capacities and mechanical strength characteristics.

The steel core may be furnished with three different coating weights of zinc. The "A" coating is the standard weight zinc coating. To provide better protection where corrosive conditions are present, heavier class "B" or "C" zinc coatings may be specified where "C" is the heaviest coating.

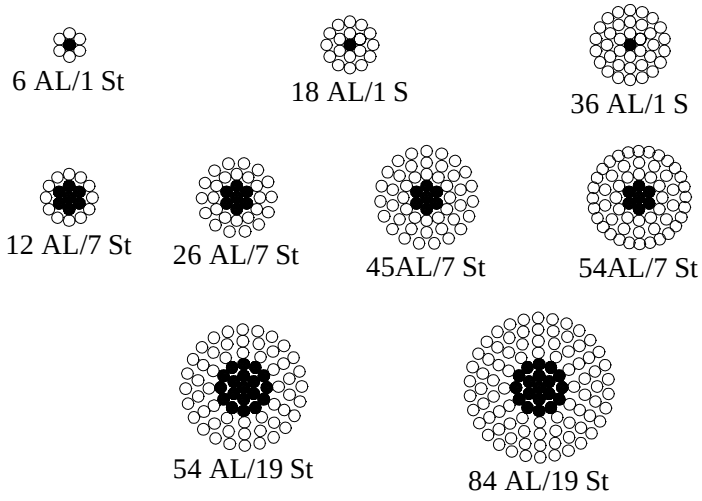


FIGURE 9-1: TYPICAL ACSR STRANDINGS

Aluminum coating is also available (not to be confused with an aluminum cladding which is thicker). There is a slight reduction in rated conductor strengths when the heavier zinc or aluminum coating is used.

9.2.2 ACSR/AW (Aluminum Conductor, Aluminum-Clad Steel Reinforced): ACSR/AW conductor is similar to conventional ACSR except the core wires are high strength aluminum-clad steel instead of galvanized steel. Aluminum-clad core wire has a minimum aluminum thickness of 20 percent of its nominal wire radius. This cladding provides greater protection against corrosion than any of the other types of steel core wire, and it is applicable for use where corrosive conditions are severe. ACSR/AW also has a significantly lower resistivity than galvanized steel core wire and may provide somewhat lower losses.

9.2.3 AAC (All Aluminum Conductors – 1350 H19): AAC conductor is made up entirely of hard-drawn 1350 aluminum strands. With a minimum aluminum content of 99.5%, 1350 aluminum is essentially pure aluminum. It is usually less expensive than other conductors, but is not as strong and tends to sag more. AAC conductors are most useful where electrical loads are heavy and where spans are short and mechanical loads are low.

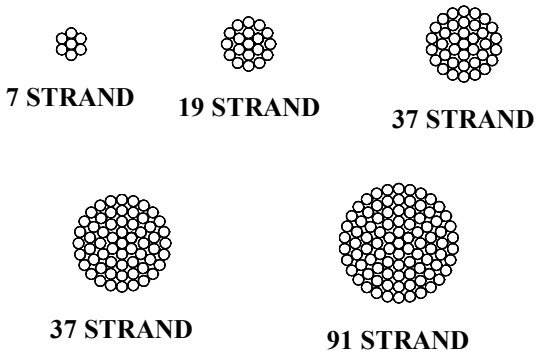


FIGURE 9-2: 1350 ALUMINUM CONDUCTOR STRANDINGS

9.2.4 AAAC-6201 (All Aluminum Alloy Conductor - 6201 Alloy): AAAC conductor is composed entirely of 6201-T81 high strength aluminum alloy wires, concentrically stranded and similar in construction and appearance to 1350 aluminum conductors. Its strength is comparable with that of ACSR. It was developed to fill the need for a conductor with higher strength than that obtainable with 1350 aluminum conductors, but without a steel core.

AAAC conductors were designed to have diameters the same as those of standard sizes and strandings of ACSR. The DC resistance of 6201 conductor is approximately equivalent to that of standard ACSR conductor with the same diameter. AAAC conductor may be used where contamination and corrosion of the steel wires is a problem. It has proven to be somewhat more susceptible to vibration problems than standard ACSR conductor strung at the same tension. The use of conductor sizes smaller than 3/0 ACSR equivalent on suspension type constructions should be avoided because the light weight of the conductor may result in inadequate downward force on the suspension insulators causing radio noise and insulator swing problems.

9.2.5 ACAR (Aluminum Conductor Alloy Reinforced): ACAR conductor consists of 1350 aluminum strands reinforced by a core of higher strength 6201 alloy. These 6201 reinforcement wires may be used in varying amounts allowing almost any desired property of strength/conductivity (between conductors using all 1350 wires and those using all 6201 wires) to be achieved. Strength and conductivity characteristics of ACAR are somewhere between those of a 1350 aluminum conductor and a 6201 conductor.

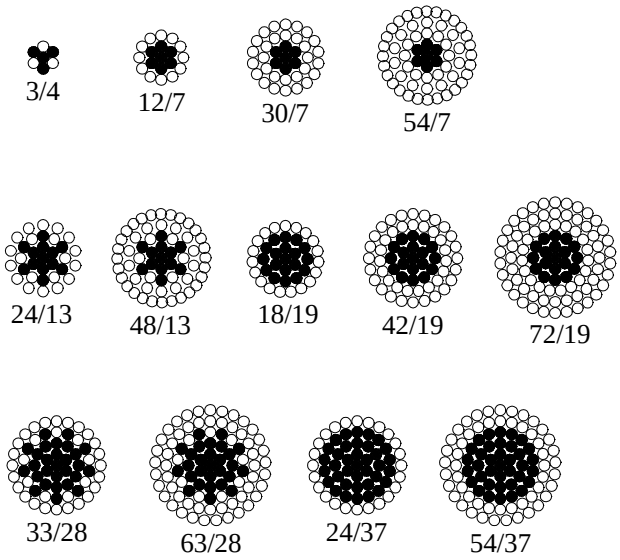


FIGURE 9-3: TYPICAL ACAR STRANDINGS

9.2.6 AWAC (Aluminum-Clad Steel Conductor): AWAC conductor is made up of aluminum-clad steel and 1350 aluminum strands. The corrosion resistant aluminum clad wires of the AWAC conductor act as strength members as well as conductivity members, thereby reducing the weight of the conductor without reducing strength. For the same designated size and stranding, the AWAC conductors have a slightly smaller diameter than standard ACSR. For smaller AWAC sizes, the ratio of aluminum-clad to aluminum strands is varied to provide a wide range of rated strengths.

9.2.7 ACSR/SD (Aluminum Conductor Steel Reinforced - Self Damping): ACSR/SD conductor may use either two layers of trapezoidal-shaped aluminum wires or two layers of trapezoidal-shaped aluminum wires and one layer of stranded round wires of hard-drawn 1350 aluminum. The steel core may be a single wire or stranded depending on the size of the conductor.

From a performance point of view, ACSR/SD conductor is similar to conventional ACSR except that it has self damping characteristics. That is, the conductor is designed to reduce aeolian vibration. The damping occurs because of the interaction between the two trapezoidal layers and between the trapezoidal layers and the core. Some special considerations associated with this conductor are that:

- During stringing, special precautions are taken and procedures followed to avoid difficulties.
- It may be more expensive than conventional ACSR, but its ability to be strung at higher tensions to reduce sag, which may result in economic advantages that offset its extra cost.

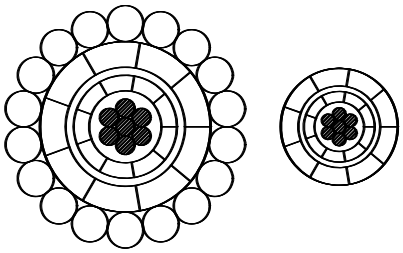


FIGURE 9-4: TYPICAL ACSR/SD STRANDINGS

9.2.8 ACSR/TW (Trapezoidal Shaped Strand Concentric - Lay Stranded Aluminum Conductors, Steel Reinforced): As with ACSR/SD, the conductor layers of ACSR/TW are trapezoidal-shaped aluminum wires. However, unlike ACSR/SD conductor, no gaps exist between layers ACSR/TW strands. The compact trapezoidal-shaped wires result in an increased capacity for an equivalent standard range of ACSR conductor diameters. Also, for a given aluminum area, a smaller conductor diameter can be designed for ACSR/TW than for equivalent round-wire ACSR which results in reduced wind-on-wire load on the structure. These are important advantages when existing transmission lines are considered for uprating or reconductoring. Other advantages and improvements of ACSR/TW include corrosion resistance and lower temperature gradient.

Use of ACSR/TW should be based on an economic evaluation to determine whether savings will be achieved in comparison with the use of conventional ACSR conductor.

9.2.9 AACSR (Aluminum Alloy Conductor, Steel Reinforced): AACSR conductor is the same as a conventional ACSR conductor except that the 1350 strands are replaced with higher strength 6201 alloy strands. The resulting greater strength of the conductor allows the sags to be decreased without exceeding the standard conductor percent tension limits. AACSR type of conductor is primarily used at river crossings where sag limitations are important. The higher tensions associated with this type of conductor require that special attention be paid to the possibility of aeolian vibration.

9.2.10 T2 (Twisted Pair Aluminum Conductor): When designing transmission lines with twisted pair (T2) type conductor, the designer should be aware of Rule 251 of NESC on conductor wind loading. The rule states for multiconductor cable an equivalent diameter of two times the single conductor diameter should be assumed for wind loading unless there is a qualified engineering study to reduce the overall cable diameter.

9.2.11 High Temperature Conductors: Three types of conductors are considered high temperature, ACCR (aluminum conductor composite reinforced), ACCC^{TM} (aluminum conductor composite core) and ACSS (aluminum conductor steel supported). For sizes equivalent to other types of conductor (*i.e.*, ACSR), higher ampacities can be achieved at similar overall sag levels while operating the conductors a much higher temperatures. One benefit of these types of conductors can be the avoided cost of replacing existing structures. The temperature ratings for these conductors can be limited by hardware, so extreme care should be used when specifying hardware and establishing operating temperature limits. Also, the unique natures of these conductors result in the use of special precautins during stringing, such as special stringing blocks in certain locations and multiple grips when installing conductors with multi-layer annealed aluminum conductor strands.

ACCR conductors are composed of heat resistant aluminum-zirconium alloy outer strands and aluminum oxide matrix core strands. . The core of the ACCR is composed of stranded fiber reinforced metal matrix, an aluminum oxide fiber embedded in high-purity aluminum. The fiber reinforced metal matrix has strength similar to steel and weight similar to aluminum. The outer strands may be round or trapezoidal in shape and are similar to 1350 aluminum ultimate strength but may be heated to high temperatures without softening (annealing) and without losing strength. Additionally, the thermal expansion of the metal matrix core has less thermal expansion than steel and retains its strength at high temperatures. ACCR conductors use similar stranding as ACSR. Because of the lightweight core, heat resistant outer and core strands, higher electrical conductivity, and lower thermal expansion for less sag, higher operating temperatures may be used with this conductor which leads to higher ampacities. ACCR conductors and hardware are usually rated up to 210 C continuous operating temperature with 240 C for short term maximum operating temperature.

ACCC™ (Aluminum Conductor, Composite Core) are composed of trapezoidal wire of 1350 aluminum stranded around the composite core. The core of the ACCC conductor is a solid with no voids and is a carbon/glass fiber polymer matrix core. This solid polymer matrix core is composed of carbon fibers surrounded by an outer shell of boron-free E-glass fibers that insulates the carbon from the aluminum conductor. The 1350 aluminum trapezoidal wires are fully annealed which make them softer compared to the hardened aluminum wires used in some other conductors. The aluminum strands are tempered because the composite core of the ACCC is designed to carry the entire load Because the core exhibits a very low coefficient of thermal expansion, the amount of sag the ACCC will experience when operating at high temperatures is considerably less than other types of conductor (*i.e.*, ACSR). ACCC ™ conductors and hardware are usually rated up to 180 C continuous operating temperature with 200 C for short term maximum operating temperature. However, because of the softer temper of the aluminum wires, the outer wires can be more susceptible to damage from improper installation and handling.

ACSS (Aluminum Conductor, Steel Supported) can be considered as another type of high temperature conductor which can be supplied with round or trapezoidal aluminum strands. ACSS conductor is similar to ACSR; however, the aluminum strands in ACSS are fully annealed and depends on the steel for its strength and sag characteristics. ACSS conductors and hardware are usually rated up to 250 C or more continuous operating temperature, depending upon the coating on the steel core, without loss of strength. However, because of the softer temper of the aluminum wires, the outer wires can be more susceptible to damage from improper installation and handling.

9.3 Selecting a Conductor Type

9.3.1 Agency Standards: The conductor selected should generally be of a type and stranding listed as being acceptable for use borrower systems of the Rural Utilities Service. See Informational Publication 202-1, "List of Materials Acceptable for Use on Systems of USDA Rural Development Electrification Borrowers".

9.3.2 Corrosion Considerations: Conductors with galvanized steel cores should not be used in areas of severe corrosion. Rather, a conductor with other types of core wire, such as mischmetal or aluminum-clad core wire should be used. A conductor with a steel core wire coated with aluminum or with a heavier weight zinc may be considered, if such materials have been successfully (*i.e.*, reliably operated without core deterioration) used in similar locations or corrosive environments..

9.3.3 Economics: The relative cost of one conductor type versus another is very important. When comparing costs, one should take overall line costs into consideration. However, a less expensive conductor with greater sags may not be a more economical selection than a more expensive conductor with lesser sag. When overall line costs are considered, the conductor that allows longer spans and shorter structures may prove to be the better choice.

9.3.4 Strength: The strength of the conductor and its ability to sustain mechanical loads without unreasonable sags must be evaluated.

9.4 Selection of Conductor Size

9.4.1 Minimum Conductor Size: Table 9-1 provides a list of minimum allowable conductor sizes for each standard agency transmission voltage. The minimums are based on a combination of radio noise, corona, and mechanical sag and strength considerations. (See Appendix I for additional details on radio noise and corona). If a conductor type other than ACSR or 6201 AAAC is used, the conductor diameter should not be less than the diameter of the ACSR specified for the particular given voltage.

TABLE 9-1
RECOMMENDED MINIMUM CONDUCTOR SIZES

kV_{LL}	ACSR	AAAC - 6201
34.5	1/0	123.3 kcmil
46	2/0	155.4 kcmil
69	3/0	195.7 kcmil
115	266.8 kcmil	312.8 kcmil
138	336.4 kcmil	394.5 kcmil
161	397.5 kcmil	465.4 kcmil
230	795 kcmil	927.2 kcmil

9.4.2 Voltage Drop Considerations: Not only should the conductor be sufficiently large to meet the requirements of paragraph 9.4.1 of this section, but it should also meet the system voltage drop requirements. Typically, the conductor impedance would have to be sufficiently low so that, under a given set of electrical loading conditions, the voltage drop would not exceed approximately 5 percent. In general, voltage drop becomes a factor for longer lines. Voltage drop can be evaluated by either running a load flow computer program or by using the estimating tables in Bulletin 1724E-201, "Electrical Characteristics of Agency Alternating Current Transmission Line Designs."

9.4.3 Thermal Capability Considerations: When sizing a phase conductor, the thermal capability of the conductor (ampacity) should also be considered. The conductor should be able to carry the maximum expected long-term load current without overheating. Generally, a conductor is assumed to be able to heat up to 167°F without any long-term decrease in strength. Above that temperature, there may be a decrease in strength depending on how long the conductor remains at the elevated temperature. A conductor's ampacity depends not only upon its assumed maximum temperature, but also on the wind and sun conditions that are assumed. See Appendix D of this bulletin for ampacity tables.

9.4.4 Economic Considerations: Economics is an important factor in determining conductor size. The minimum conductor sizes given in Table 9-1 will rarely be the most economical in the long run. The added cost of a larger conductor may be more than offset by the present worth of the savings from the lower line losses during the entire life of the conductor. A proper economic analysis should at a minimum consider the following factors for each of the conductor sizes considered:

- The total per mile cost of building the line with the particular conductor being considered;
- The present worth of the energy losses associated with the conductor;
- The capital cost per kilowatt of loss of the generation, substation and transmission facilities necessary to supply the line losses;
- Load growth.

The results of an economic conductor analysis can often be best understood when presented in a graphical form as shown in Figure 9-5. At an initial load of approximately 200 MW, 1272 kcmil becomes more economical than 795 kcmil. 954 kcmil is not economical at any load level included on the graph.

9.4.5 Standardization and Stocking Considerations: In addition to the above factors, the problem of standardization and stocking should be considered. When a conductor is electrically and economically optimum, but is not a standard size already in use on the system, the additional cost and complications of having one more conductor size to stock should be weighed against the advantages of using the optimum conductor. A proliferation of conductor sizes in use on a power system is undesirable because of the expense of stocking many sizes. In addition, if a power system does not standardize on conductors then there may be a need for additional associated hardware such as end fittings and splices.

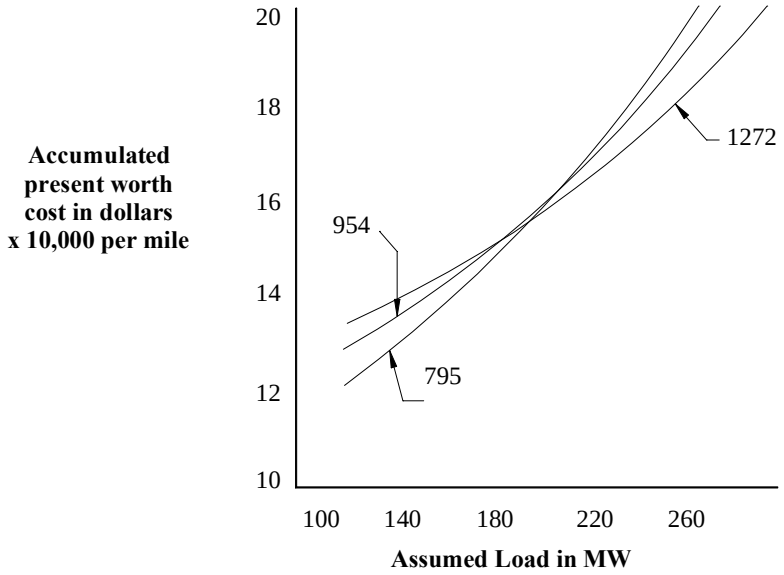


FIGURE 9-5: RESULTS OF A TYPICAL ECONOMICAL CONDUCTOR ANALYSIS – 230 kV, 795 vs. 954 vs. 1272 kcmil ACSR

9.5 Overhead Ground Wires (OHGW)

9.5.1 High Strength or Extra High Strength Galvanized Steel Wires: High strength OHGW included in Informational Publication 202-1 are 3/8" and 7/16", while extra high strength listed sizes include 5/16", 3/8", and 7/16". Siemens Martin grade wires of any size and 1/4" steel strand are not accepted by the agency for use as overhead ground wires. Overhead ground wires are required to be in full compliance with ASTM A-363, "Standard Specification for Zinc-Coated (Galvanized) Steel Overhead Ground Wire Strand," ASTM A-363 does not allow steel wires to have brazed or welded joints. Steel wires for overhead ground wires are available in three weights of zinc coating. The standard weight zinc coating is designated as 'A'. The heavier zinc coating is designated 'B' and 'C', with 'C' having the heaviest weight of zinc.

9.5.2 Aluminum-Clad Steel Strand: A thick cladding of aluminum which makes aluminum-clad steel strand more resistant to corrosion than strands with a thin coating of zinc. In addition, the aluminum clad material has greater conductivity.

The sizes of this material that may be used as overhead ground wires are 7 No. 10AWG, 7 No. 9AWG, 7 No. 8AWG, and 7 No. 7AWG. The material is in accordance with ASTM B416, "Standard Specification for Concentric-Lay-Stranded Aluminum-Clad Steel Conductors."

9.5.3 Selecting a Size and Type: Selecting an overhead ground wire size and type is dependent upon only a few factors, the most important of which is how the sag of the OHGW coordinates with that of the phase conductors. Other factors that may have to be considered are corrosion resistance and conductivity.

If a line is to be built in a seacoast region or in another location where there is a highly corrosive atmosphere, aluminum-clad steel wire should be considered. If the OHGW is to be used to carry any type of communications signal, or if large magnitudes of lightning stroke currents are expected, a higher conductivity than normal may be desirable.

9.6 Conductor and Overhead Ground Wire Design Tensions

9.6.1 General: Throughout the life of a transmission line, the conductor tensions may vary between 10 and 60 percent, or more, of rated conductor strength due to change in loading and temperature. Most of the time, however, the tension will vary within relatively narrow limits, since ice, high winds, and extreme temperatures are relatively infrequent in many areas. Such normal tensions may actually be more important in determining the life of the conductor than higher tensions which are experienced infrequently.

9.6.2 Conductor Design Tensions: In Table 9-3 provides recommended maximum conductor tension values for ACSR and 6201 AAAC conductors that should be observed for the ruling span. Note that the values given are maximum design values. If deemed prudent, tensions less than those specified or loadings greater than the standard loading condition (tension limit for condition 3 of Table 9-3) may be used. However, it is unwise to base the selection of a "maximum loading" condition on a single or very infrequent case of excessive loading. Mountainous areas above 4000 feet in which ice is expected, should be treated as being in heavy loading district even if they are not.

In open areas where steady winds are encountered, aeolian vibration can be a problem, especially if conductor tensions are high. Generally, lower tensions at conditions at which aeolian vibration is likely to occur, can reduce vibration problems (see paragraph 9.9.2 for further discussion).

Explained below are the several conditions at which maximum conductor tension limits are specified.

1. Initial Unloaded Tension: Initial unloaded tension refers to the state of the conductor when it is initially strung and is under no ice or wind load.

2. Final Unloaded Tension**:** After a conductor has been subjected to the assumed ice and wind loads, and/or long time creep, it receives a permanent or inelastic stretch. The tension of the conductor in this state, when it is again unloaded, is called the final unloaded tension.

3. Standard Loaded Tension: The standard loaded tension refers to the state of a conductor when it is loaded to the assumed simultaneous ice and wind loading for the NESC loading district concerned (see Table 11-1, Chapter 11 for the loads associated with each loading districts). The constants in Table 9-2 are to be added to the vector resultant of the transverse and vertical loads to get the total load on the conductor:

TABLE 9-2
CONSTANTS TO BE ADDED TO THE TOTAL
LOAD ON A WIRE FOR NESC DISTRICT LOADS

Heavy	Medium	Light
0.30 lbs/ft.	0.20 lbs/ft.	0.05 lbs/ft.

In cases where the standard loaded condition is the maximum mechanical load used in the calculations, the initial and final sags and tensions for the standard loaded condition will be the same unless creep is the governing factor. If another condition, such as extreme ice, is the maximum mechanical load, then the initial and final sags and tensions for the standard loaded condition can be significantly different from one another. In this case, it is important that the loaded tension limits be set for initial conditions.

4. Extreme Wind Tension**:** The extreme wind tension refers to the state of the conductor when a wind is blowing on it with a value not less than the 50-year mean recurrence interval (see Figure 11-3 in Chapter 11 of this bulletin). No ice should be assumed to be on the conductor.

5. Extreme Ice Tension**:** The tension in a conductor when it is loaded with an extreme amount of ice for the area concerned is called the extreme ice tension. It should be assumed that there is no wind blowing when the ice is on the conductor. Values of 1 to 2 in. of radial ice are commonly used as extreme ice loads.

6. Extreme Ice with Concurrent Wind: The tension in a conductor when it is loaded with an extreme ice with a concurrent wind (see Figure 11-3 in Chapter 11 of this bulletin).

9.6.3 Controlling Conditions: For a given ruling span, usually only one of the tension limit conditions will control the design of the line and the others will have relatively little significance as far as line tensions are concerned.

If the conductor loading under extreme ice or wind loads is greater than under the standard loaded condition, calculated sag and tension values at other conditions could be somewhat different from what they would be if the standard loaded condition were the maximum case. In these situations, stringing sags should be based upon tension limits for tension conditions 1, 2, and 3 only, as tensions at conditions 4 and 5 are satisfactory.

9.6.4 Overhead Ground Wire (OHGW): To avoid unnecessarily high mechanical stresses in the OHGW, supporting structures, and guys, the OHGW should not be strung with any more tension than is necessary to coordinate its sags at different conditions with the phase conductors. See Chapters 6 and 8.

TABLE 9-3
RECOMMENDED CONDUCTOR AND OVERHEAD
GROUND WIRE TENSION AND TEMPERATURE LIMITS (Note B)

Temperatures

- Tension limits for conditions 1, 2 and 3 below are to be met at the following temperatures:
  - Heavy loading district 0º F
  - Medium loading district 15º F
  - Light loading district 30º F
- Tension limits for condition 4 are to be met at the temperature at which the extreme wind is expected.
- Tension limits for condition 5 & 6 are to be met at 32º F

Tension Condition (See section 9.6.2 for explanation)	Tension Limits (percentage of rated breaking strength)		
	Conductor	OHGW High Strength Steel	OHGW Extra High Strength Steel
1. Maximum initial unloaded	33.3 (Note C)	25	20
2. Maximum final unloaded	25 (Note D)	25	20
3. Standard Loaded (usually NESC district loading)	50	50	50
4. Maximum extreme wind (Note A)	70 (Note E)	80	80
5 . Maximum extreme ice (Note A)	70 (Note E)	80	80
6. Extreme ice with concurrent wind	70 (Note E)	80	80

Notes:

(A) These limits are for tension only. When conductor stringing sags are to be determined, tension limits 1, 2 and 3 should be considered as longs as tensions at conditions 4, 5 and 6 are satisfactory.

(B) Tension limits do not apply for self-damping and other special conductors.

(C) In areas prone to aeolian vibration, a value of approximately 20 percent at the average annual minimum temperature is recommended, if vibration dampers or other means of controlling vibration are not used (see section 9.9 for further details).

(D) For 6201 AAAC, a value of 20 percent is recommended.

(E) For ACSR only. For 6201 Aluminum, use 60 percent.

9.7 Ruling Span

9.7.1 Why a Ruling Span? If all spans in a section of line between deadends are of the same length, uniform ice and wind loads will result in equal conductor tension in all spans. But span lengths usually vary in any section of line, with the result that temperature change and ice and wind loads will cause conductor tensions to become greater in the longer spans and less in the shorter spans when compared to the tensions of loaded uniform spans. Movement of insulator strings and/or flexing of the structures will tend to reduce this unequal tension. It is possible, however, for conductor tension in long spans to reach a value greater than desired unless the line is spotted and the conductor strung to limit this undesirable condition.

A ruling span is an assumed uniform design span which approximately portrays the mechanical performance of a section of line between its deadend supports. The ruling span is used in the design and construction of a line to provide a uniform span length which is representative of the various lengths of spans between deadends. This uniform span length allows sags and clearances to be readily calculated for structure spotting and conductor stringing.

Use of a ruling span in the design of a line assumes that flexing of the structure and/or insulator string deflection at the intermediate supporting structures will allow for the equalization of tension in the conductor between adjacent spans to the ruling span tension.

9.7.2 Calculations of the Ruling Span: On a line where all spans are equal, the ruling span is the same length as the line spans. Where spans vary in length, the ruling span is between the shortest and the longest span lengths on the line, but is mainly determined by the longer spans.

- Approximate Method. Some judgment should be exercised in using this method since a large difference between the average and maximum span may cause a substantial error in the ruling span value.

$$RS = L_{avg} + 2/3\left(L_{\max} - L_{avg}\right) \qquad \text{Eq. 9-1}$$

where:

RS = ruling span in feet.
L_{avg} = average span in a line segment between deadends, in feet.
L_{max} = maximum span in a line segment between deadends, in feet.

- Exact Method. The following is the exact formula for determining the ruling span in a line segment between deadend structures:

$$RS = \sqrt{\frac{L_1^{\,3} + L_2^{\,3} + L_3^{\,3} + \ldots + L_n^{\,3}}{L_1 + L_2 + L_3 + \ldots + L_n}} \qquad \text{Eq. 9-2}$$

where:

L_1, L_2, L_3, etc. = the different span length in the line segment, in feet

Other symbols are as previously defined.

9.7.3 Establishing a Ruling Span: As can be seen from Equation 9-2, the exact value of the ruling span can only be calculated after the structures have been spotted and all the span lengths determined. However, the ruling span has to be known in advance of structure spotting. Thus the ruling span needs to be **estimated** before spotting structures on the plan-profile drawings.

When following any procedure for estimating ruling span, keep in mind that estimation of a ruling span is an intuitive process based on experience, judgment, and trial and error. A good starting point for estimating ruling span is the height of the base structure. The base structure is the structure that is expected to occur most often throughout the line. After assuming a base structure height, subtract the minimum ground clearance value from the height of the lowest phase conductor above ground at the structure. The allowable sag as limited by ground clearance is the result. Using this sag value and tables of sags for various ruling span lengths, a ruling span length can be chosen whose sag is approximately equal to the allowable sag for the base structure height. In other words, a ruling span is chosen to be approximately equal to the level ground span -- the maximum span limited by line-to-ground conductor clearance for a particular height structure. This method of choosing a ruling span is useful if the terrain is flat or rolling. However, if it is rough, the ruling span should be somewhat greater than the level ground span.

The ruling span value initially chosen should be checked to see that it coordinates reasonably well with the minimum span values as limited by such factors as structure strength, conductor separation, galloping, etc. Also, Equation 9-1 should be used in conjunction with estimated maximum and average span values to further check the reasonableness of the estimated ruling span. If the initial estimate does not check out, the value should be changed and the procedure repeated.

In cases where the spans in one extended section of line are consistently and considerably longer or shorter than in another section of line, use of more than one ruling span may be unavoidable. It is a common practice to permit long spans to double the average span without deadends, provided conductor tension limits are satisfactory. In addition, short spans should not be less than approximately one-half of the ruling span. After the plan and profile sheets are plotted, the validity of the estimated ruling span value should be checked by comparing it to the actual value obtained. It is not essential that the estimated ruling span value be equal to the actual value, provided the estimated ruling span results in satisfactory ground clearance and economical structure spotting without excessive conductor tensions. However, if the difference between the estimated and actual ruling span is more than approximately 15 percent, the effects resulting from the difference should be carefully checked.

9.7.4 Effects of the "Wrong" Ruling Span: It is important that the actual ruling span be reasonably close to the ruling span value that is used to spot the line. If this is not the case, there may be significant differences between the predicted conductor tensions and clearances and the actual values. There have been instances where sags were greater than predicted, resulting in clearance problems, because the wrong ruling span was assumed. Table 9-4 will be of use in determining how conductor sags differ from the predicted value when there are differences between actual and assumed ruling span. Note that tension variation is opposite of that of the sags. Thus, increased sags mean decreased tension and vice versa.

TABLE 9-4
DIRECTION OF DEVIATION OF SAGS FROM
PREDICTED VALUES WHEN ACTUAL AND ASSUMED (DESIGN)
RULING SPAN VALUES ARE SIGNIFICANTLY DIFFERENT
(Applies to Unloaded Condition)

	Assumed RS is greater than Actual RS	**Assumed RS is less than Actual RS**
Conductor temperature is less than temperature at which the conductor was strung	Actual sag is less than predicted-- *INCREASED TENSIONS*	Actual sag is greater than predicted-- *CLEARANCE PROBLEMS*
Conductor temperature is greater than temperature at which the conductor was strung	Actual sag is greater than predicted-- *CLEARANCE PROBLEMS*	Actual sag is less than predicted-- *INCREASED TENSIONS*

CLEARANCE PROBLEMS – Conductor sags greater than indicated on the plan and profile sheets may result in clearance problems

INCREASED TENSIONS – Conductor tensions greater than anticipated will result

9.8 Determining Conductor Sags and Tensions: Determination of conductor sags and tensions, given a set of tension limits as outlined in section 9.6, is a complex and difficult task. This is true because only one of the tension limits may control, and it is not always predictable which limit it will be. In addition, it is necessary to work with conductor stress strain curves which for a compound conductor such as ACSR can be rather complex.

The best method of obtaining conductor sag and tension values is to use one of the numerous computer programs written for that purpose. When using a computer program, several factors should be checked:

- The program should be written so that a check is made of all the limiting conditions simultaneously and the governing condition noted.
- The program should take conductor creep into account.
- The tension values given should be average tension values and not tension at support or horizontal tension values.
- The source of the stress stain data used should be indicated.

If computerized sag tension values are not available from the software, values can be generated using the graphical method given in the publication, "Graphic Method for Sag Tension Calculations for ACSR and Other Conductors," Publication No. 8, Aluminum Company of America, 1961.

9.9 Aeolian Vibration

9.9.1 General: Overhead conductors of transmission lines are subject to aeolian and galloping, both of which are produced by wind. Galloping is discussed in section 6.3. Aeolian vibration is a high-frequency low-amplitude oscillation generated by a low velocity, comparatively steady wind blowing across the conductors. This steady wind will create air vortices or eddies on the lee side of the conductor. These vortices or eddies will detach at regular intervals from the top and bottom area of the conductor creating a force on the conductor that is alternately impressed from above and below. If the frequency of the forces approximately corresponds to a frequency of a mode of resonant vibration of the span, the conductor will tend to vibrate in many loops in a vertical plane. The frequency of vibration depends mainly on conductor size and wind velocity and is generally between 5 and 100 Hz for wind speeds within the range of 0 to 15 miles per hour. The peak-to-peak amplitudes of vibration will cause alternating bending stresses great enough to produce fatigue failure in the strands of the conductor or OHGW at the points of attachment. Highly tensioned conductors in long spans are particularly subject to vibration fatigue. This vibration is generally more severe in flat open terrain where steady winds are more often encountered.

The frequency and loop length of the vibration can be determined using equation 9-3.

Frequency of the vibration:

$$f = 3.26\frac{V}{d_c} \qquad \text{Eq. 9-3}$$

where:

f = frequency of conductor vibration in Hertz
V = transverse wind velocity in miles per hour
d_c = conductor diameter in inches

Loop Length (for a conductor that is assumed to have negligible stiffness):

$$LL = \frac{1}{2f}\sqrt{\left(\frac{(T_{avg})(g)}{w_c}\right)} \qquad \text{Eq. 9-4}$$

where:

LL = loop length in feet
T_{avg} = average conductor tension in pounds
w_c = unit weight of conductor in pounds per foot$_2$
g = universal gravitational constant, 32.2 ft/sec

Other symbols are as previously defined.

9.9.2 Designing for Vibration Problems: If an area is expected to have aeolian vibration problems, measures ‘a’ through ‘d’ may be taken to mitigate possible problems with damage to conductors, shield wire, and hardware. It is also important to note that structures, not just conductors, shield wires, and hardware, may be adversely affected by vibration. The measures are not necessarily mutually exclusive; more than one measure may be used simultaneously.

a. Reduced Tension: The two line design variables that have the greatest effect upon a line's vibration characteristics are conductor tension and span length. Singly or in combination, these two variables can be reduced to the point where the level of vibration, without any vibration damping devices, will not be damaging. For similar sag characteristics, conductors of different types, with their different characteristics, may require a different degree of vibration protection.

   A rule of thumb that has proved generally successful in eliminating vibration problems is to keep the conductor tension for short and medium length spans under initial unloaded conditions at the average annual minimum temperature to approximately 20 percent or less of the conductor's rated strength. For long spans, a somewhat lower percent tension limit should be used. Due to their vibration characteristics, 6201 AAAC and 1350 aluminum conductors should be held to tensions somewhat lower than the 20 percent value, even for relatively short spans.

b. Armor Rods: In addition to reinforcing the conductor at the support points, armor rods provide a small amount of damping of aeolian vibration. In lines with lower conductor tension and shorter spans, this damping may provide adequate protection against conductor strand fatigue.

c. Cushioned Suspensions: Cushioned suspensions combine armor rods with a resilient cushioning of the conductor. These suspension clamps provide somewhat more damping than armor rods, but the degree of damping is still relatively small compared to vibration dampers.

d. Dampers: Stockbridge and other types of dampers are effective devices for controlling vibration. The selection of damper sizes and the best placement of them in the spans should be determined by the damper or conductor manufacturer on the basis of the tension, weight, and diameter of the conductor and the expected range of wind velocities. The length of the suspension clamp and the effect of the armor rods or cushioned suspensions should also be considered. With new efficient damper designs and usual conductor tensions and span lengths, one damper is installed near one span support joint. For long spans, additional dampers may be required.

9.10 Galloping: See Chapter 6 for details.

9.11 Maximum Possible Single Span: For a given span length, as the sag is increased, the tension at the support will decrease, until a point is reached where the tension will begin to increase due to the weight of the conductor. This point occurs when the sag is equal to 0.337 times the span length.

The relationship between span length and tension can be expressed as:

$$L_{\max} = 1.33\frac{T}{w_c} \qquad \text{Eq. 9-5}$$

where:

w_c = unit weight of conductor in pounds per foot
T = resultant tension at support, pounds
L_{max} = maximum span, feet

The above formula can be used to determine the maximum possible span given a maximum tension at supports. This is most useful when dealing with river crossings, etc.

9.12 Sag and Tension Relationships: The relationships in paragraphs 9.12.1 through 9.12.3 are useful for understanding the sag-tension relationships for conductors:

9.12.1 Level Span Sags: Equation 9-6, the approximate "parabola method", is helpful in solving some sag and tension problems in span lengths below 1,000 feet, or where sag is less than 5 percent of the span length.

$$S = \frac{w_c L^2}{8T_h} \qquad \text{Eq. 9-6}$$

where:

S = sag at center of span in feet
L = span length in feet
T_h = horizontal tension in pounds

The exact formula for determining sags is:

$$S = \frac{T_h}{w_c}\left(\cosh\frac{w_c L}{2T_h} - 1\right) \qquad \text{Eq. 9-7}$$

9.12.2 Inclined Span Sags: See Figure 9-6 for method of determining inclined span sags.

9.12.3 Tension: The conductor tension in a level span varies from a maximum value at the point of support to a minimum value at mid-span point.

The tension at the point of support is:

$$T = T_h + w_c S = T_h \cosh\frac{w_c L}{2T_h} \qquad \text{Eq. 9-8}$$

The value that is generally referred to, when the "tension" of a conductor is indicated, is usually the average of the tension at the support and the tension at mid-span. Thus:

$$T_{avg} = \frac{T_h + T}{2} = T_h + \frac{w_c S}{2} \qquad \text{Eq. 9-9}$$

where:

T_{avg} = average tension in pounds

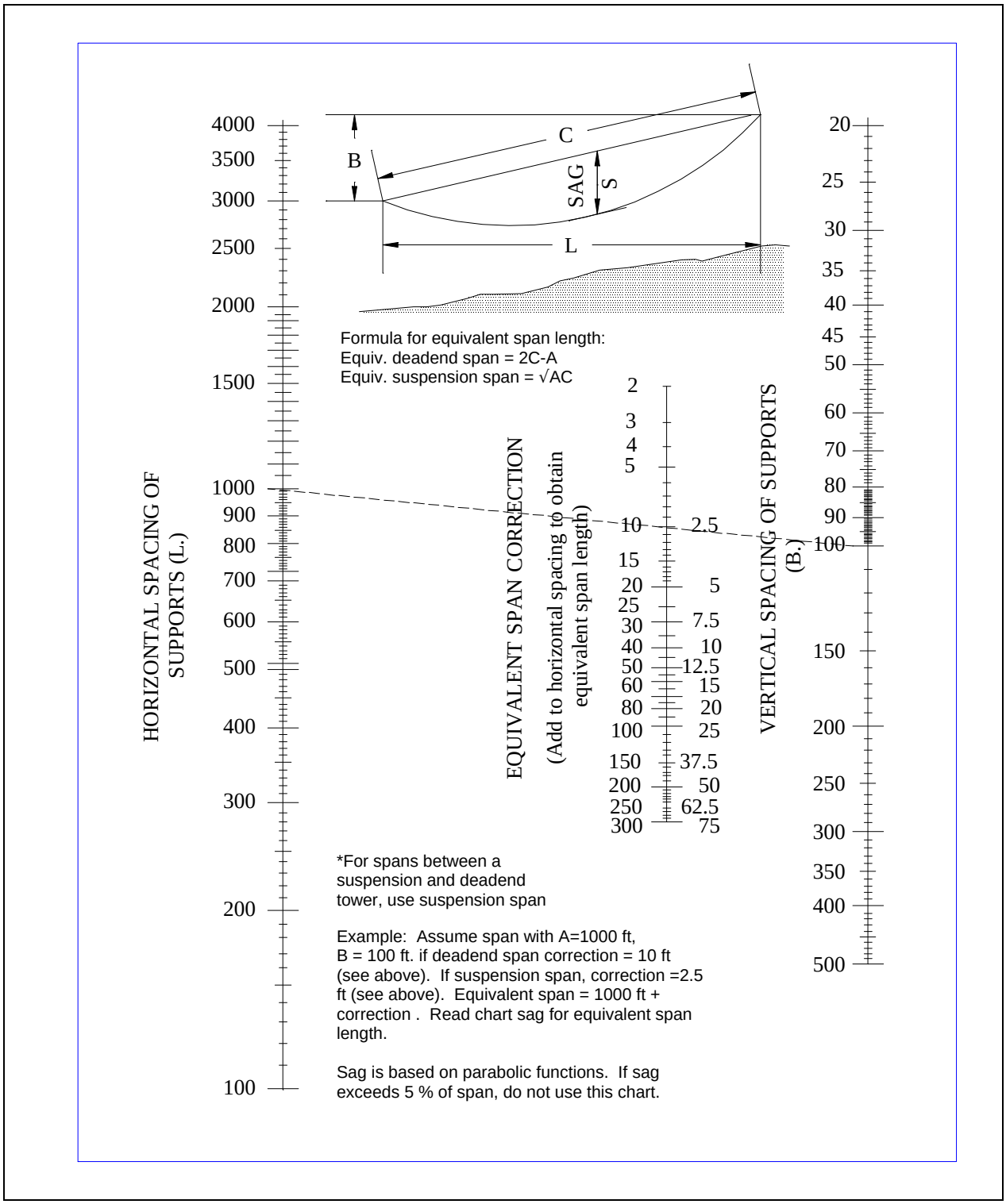


FIGURE 9-6: NOMOGRAPH FOR DETERMINING LEVEL SPAN EQUIVALENTS OF NON-LEVEL SPANS

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9.13 Stringing Conductors

9.13.1 Tension Method (Preferred) for Stringing Conductors: Using this method, the conductor is kept under tension during the stringing process. Normally, the tension method is used to keep the conductor clear of the ground and of obstacles which might cause conductor surface damage and clear of energized circuits. The method requires pulling a light pilot line into the sheaves. The pilot line is then used to pull a heavier line. The heavier pulling line is used to pull conductors from reel stands using specially designed tensioners and pullers. For lighter conductors, a lightweight pulling line may be used in place of the pilot line to directly pull the conductor. A helicopter or ground vehicle can be used to pull or lay out a pilot line or pulling line. When a helicopter is used to pull a line, synthetic rope is normally used to attach the line to the helicopter and prevent the 'pilot line' or pulling line from flipping into the rotor blades upon release. With the tension method, the amount of right-of-way travel by heavy equipment can be minimized. Usually, this tension method provides the most economical means of stringing conductor. Use of a helicopter is particularly advantageous in rugged or poorly accessible terrain.

Major equipment required for tension stringing includes reel stands, tensioner, puller, reel winder, pilot line winder, splicing cart and helicopter or pulling vehicle.

9.13.2 Slack or Layout Method: Using this method, the conductor is dragged along the ground by means of a pulling vehicle, or the reel is carried along the line on a vehicle and the conductor is deposited on the ground. Conductor reels are positioned on reel stands or "jacks," either placed on the ground or mounted on a transport vehicle. These stands are designed to support the reel on an arbor, permitting the reel to turn as the conductor is pulled. Usually a braking device is provided to prevent overrunning and backlash. When the conductor is dragged past a supporting structure, pulling is stopped and the conductor placed in sheaves attached to the structure before proceeding to the next structure.

This method is chiefly applicable to the construction of new lines where maintenance of conductor surface condition is not critical and where terrain is easily accessible to a pulling vehicle. The method is not usually economically applicable in urban locations where hazards exist from traffic or where there is danger of contact with energized circuits, nor is it practical in mountainous regions inaccessible to pulling vehicles.

Major equipment required to perform slack stringing includes reel stands, pulling vehicle(s) and a splicing cart.

9.13.3 Stringing Conductors During Temperature Changes: An examination of conductor sag and tension tables will generally indicate the changes that take place in various span lengths with a change of conditions. For a given set of conditions, spans of various lengths may have a different rate of tension change with a change of loading or temperature. The ruling span tension of an unloaded conductor matches the tension of any other span only at one temperature. Large changes in temperature during stringing require care in matching average tensions in any section. It is desirable to complete stringing between deadends during periods of minimum temperature change and at zero wind load. Where spans are supported by suspension insulators, each span will have an influence on adjacent spans such that no span can be considered independently of the remainder of spans in the same section between anchor structures. Change in temperature has a greater effect on short spans than loading does, while long spans are affected more by loading. In short spans a slight movement of supports results in substantial changes in tension while in longer spans, relatively greater movement is required. The relation between adjacent span lengths therefore determines the movement required to equalize tension.

9.14 The Sagging of Conductors: It is important that the conductors be properly sagged in at the right stringing tension for the ruling span used. When installing conductors, a series of several spans is usually sagged in one operation by pulling the conductors to proper tension while they are supported on free rolling sheaves. To obtain the correct sags and to ensure that the suspension insulators will hang vertically, the horizontal components of tension must be the same in all spans for a selected condition. In a series of spans of varying length, greater sag tends to form in the long spans. On steep inclines the sheaves will deflect in the uphill direction and there will be a horizontal component of tension in the sheave itself. The horizontal component of tension in the conductor will therefore increase from one span to the next, as the elevation increases, by an amount equal to the horizontal component in the sheave. As a result, sags will proportionally decrease. In order to avoid this effect, it may be necessary to use a procedure called offset clipping. In this procedure, the point along the conductor at which it is attached to the insulator string is moved a specific distance down span from the point at which the conductor sits in the stringing block. See Figure 9-7 for further details on offset clipping.

It is important that the sags of the conductor be properly checked. It is best to do this in a series of level spans as nearly equal to the ruling span as possible.

For additional information, see:

> "A Guide to the Installation of Overhead Transmission Line Conductors," IEEE Standard 524-1992, IEEE, 1992.

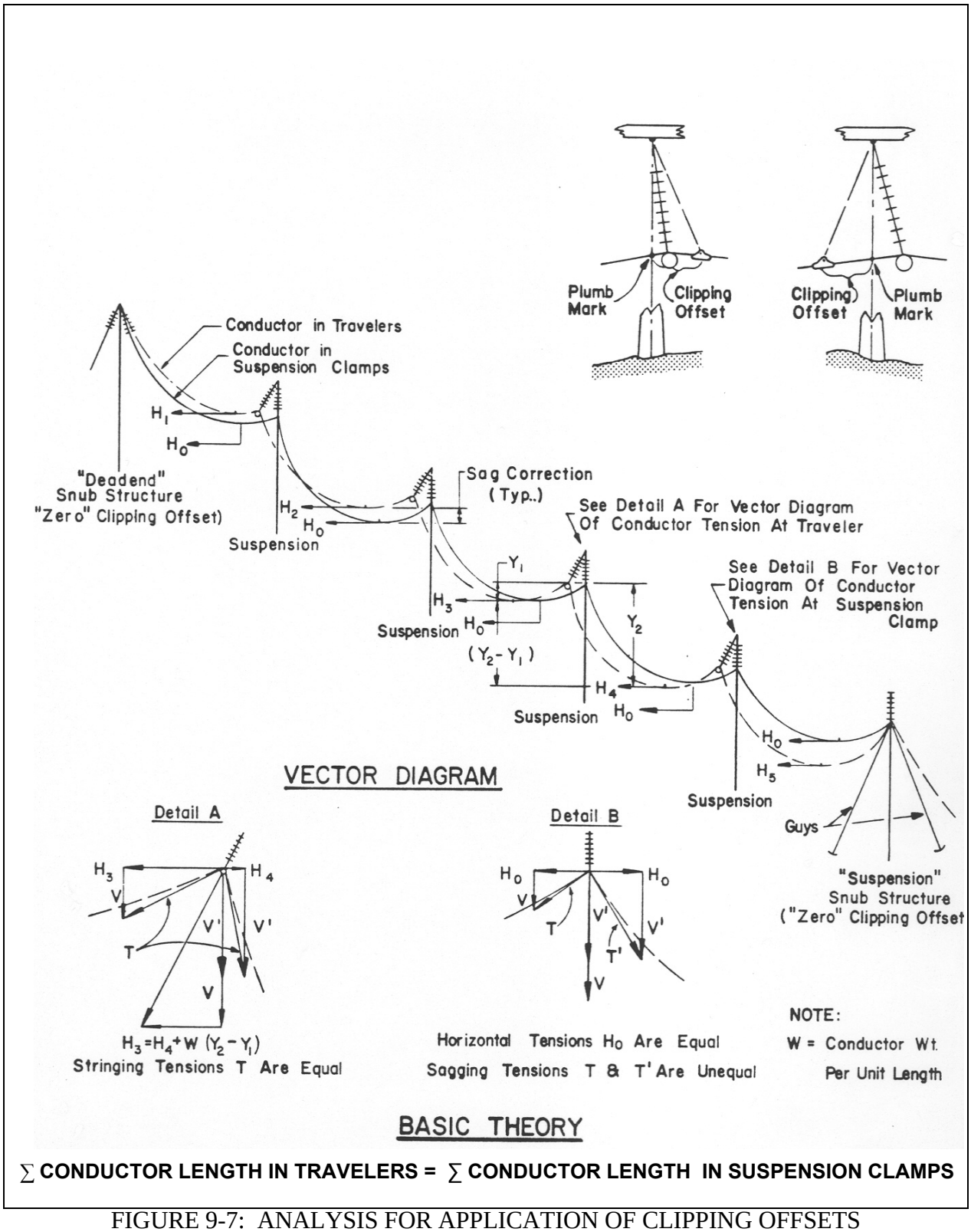

FIGURE 9-7: ANALYSIS FOR APPLICATION OF CLIPPING OFFSETS

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9.15 Example 9-1: Determination of Ruling Span: Determine the ruling span for the line segment given below using both the exact and approximate method.

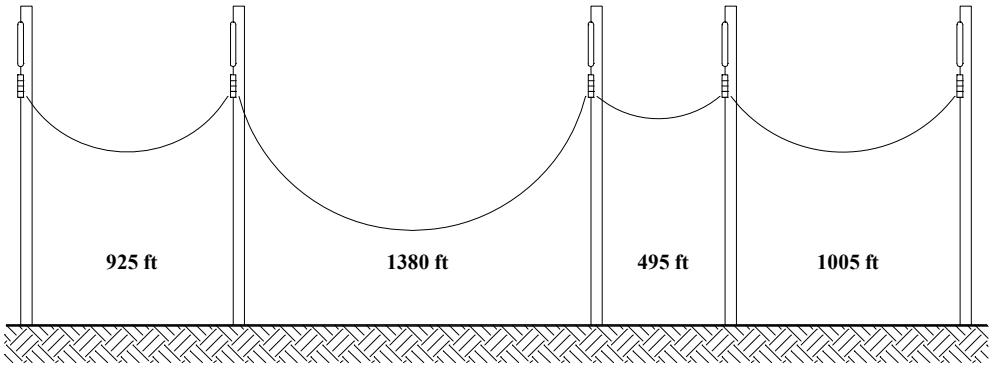


FIGURE 9-8: LINE SECTION FOR EXAMPLE 9-1

Solution, Exact Method:

$$RS = \sqrt{\frac{L_1^{\,3} + L_2^{\,3} + L_3^{\,3} + \ldots + L_n^{\,3}}{L_1 + L_2 + L_3 + \ldots + L_n}}$$ See Eq. 9-2

$$RS = \sqrt{\frac{925^3 + 1380^3 + 495^3 + 1005^3}{925 + 1380 + 495 + 1005}}$$

RS = 1094 ft.

Solution, Approximate Method**:**

$RS = L_{avg} + 2/3(L_{max} - L_{avg})$ See Eq. 9-1

$L_{avg} = (925 + 1380 + 495 + 1005)/4 = 951$ ft.

$L_{max} = 1380$

$RS = 951 + 2/3(1380 - 951)$

RS = 1237 ft.

As previously mentioned in the text, the error between the exact and approximate methods of determining ruling span is caused by a rather significant error between the average and maximum span values.

9.16 Example 9-2, Maximum Span Determination: Determine the maximum span (for river crossings, etc.) for a 795 kcmil 26/7 ACSR conductor. Assume that under heavy loading district conditions, the conductor can be loaded up to 40 percent of its rated strength.

Solution**:** From the conductor tables in Appendix B, the rated strength of the conductor is 31,500 lbs. and the weight of the conductor with 1/2 in. of radial ice is 2.0930 lbs/ft..

T = 31500(0.4) = 12600 lbs.

$$L_{\max} = 1.33\frac{T}{w_c}$$ See Eq. 9-5

L_{max} = 1.33 $\frac{12600 \text{ lbs.}}{2.0930 \text{ lbs/ft.}}$ = 8007 ft.

9.17 Example 9-3, Determination of Tensions at the Mid Span Point and at the Point of Support: A level 800 ft. span of 795 kcmil 26/7 ACSR conductor has a sag of 21.95 ft. The average tension value is 9,185 lbs. and there is no ice or wind on the conductor. Determine the actual tension values at the mid span point and at the point of conductor support.

Solution for the Tension at Mid Span Point:

$$T_{avg} = \frac{T_h + T}{2} = T_h + \frac{w_c S}{2}$$ See Eq. 9-9

$$T_h = T_{avg} - \frac{w_c S}{2}$$

From the conductor tables in Appendix B, the weight of the conductor without ice is 1.0940 lbs/ft.

T_h = 9185 - $\frac{(1.094)(21.95)}{2}$

T_h = 9173 lbs.

Solution for the Tension at Support:

$$T = T_h + w_c S = T_h \cosh\frac{w_c L}{2T_h}$$ See Eq. 9-8

$T = T_h + w_c S$

T = 9173 + (1.094)(21.95)
T = 9197 lbs.

10. PLAN-PROFILE DRAWINGS

10.1 General: Transmission line plan-profile drawings serve an important function in linking together the various stages involved in the design and construction of the line. Initially, the drawings are prepared based on a route survey. These drawings show the location and elevation of all natural and man-made features to be traversed by, or which are adjacent to, the proposed line which may affect right-of-way, line design and construction. They also indicate ownership of lands near the line. The drawings are then used to complete line design work such as structure spotting. During material procurement and construction, the drawings are used to control purchase of materials and they serve as construction specification drawings. After construction, the final plan-profile drawings become the permanent record and right-of-way data, useful in line operation and maintenance or future modifications.

Accuracy, clarity, and completeness of the drawings should be maintained, beginning with initial preparation, to ensure economical design and correct construction. All revisions made subsequent to initial preparation and transmittal of drawings should be noted in the revision block by date and brief description of revision. Originals of the plan-profile drawings, revised for as-built conditions, should be filed by the borrower for future reference.

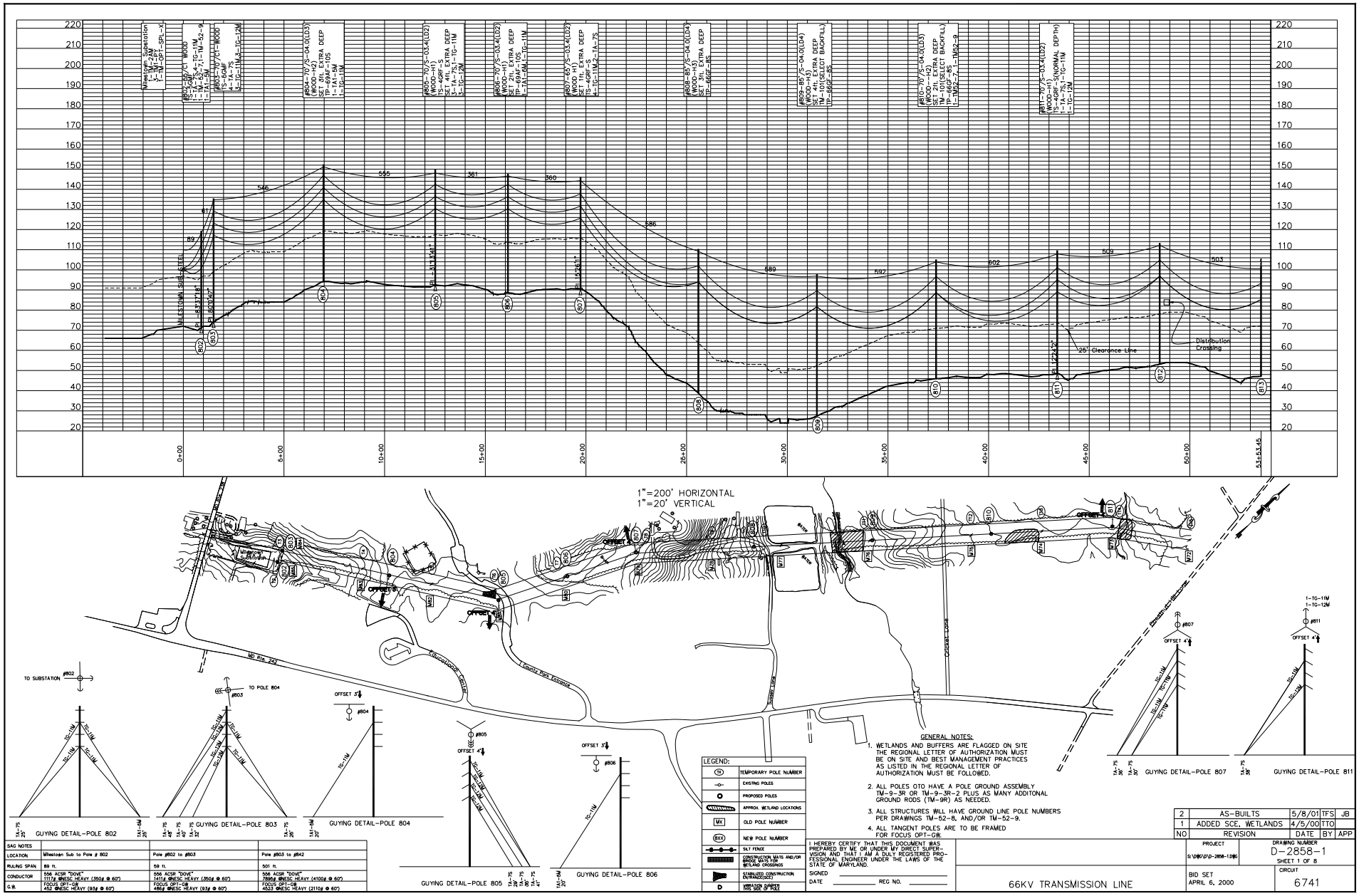
10.2 Drawing Preparation: Adequate control of field survey, including ground check of aerial survey, and proper translation of data to the plan-profile drawings are of utmost importance. Errors which occur during this initial stage will affect line design because a graphical method is used to locate the structures and conductor. Normally, plan-profile sheets are prepared using a scale of 200 feet to the inch horizontally and 20 feet to the inch vertically. On this scale, each sheet of plan-profile can conveniently accommodate about 1 mile of line with overlap to connect the end span on adjacent sheets. On lines with abrupt ground terrain changes and on lines where there is need to minimize breaks in elevation view, plan-profile sheets may use a scale of one inch equal to 400 feet horizontally and one inch equal to 40 feet vertically may be used.

A sample format for plan-profile drawing, detailing dimensions and stationings in U.S. customary (English) units, is shown in Figure 10-1. Stationing and structure numbering increases from left to right and the profile and corresponding plan view are included on the same sheet. Drawings prepared in ink on Mylar or tracing cloth will provide a better permanent record than on paper. However, structure spotting initially should be marked in pencil on plan-profile drawing paper and transferred to the base tracings in ink after the drawings are approved and the line is released for construction.

Conventional symbols used to denote features on the drawings are shown in Figure 10-2. Features of existing obstacles, structures, etc. to be crossed by the transmission line, including the height and position of power and telecommunication lines, should be shown and noted by station and description in both the plan and profile views. The magnitude and direction of all deflection angles in the line should be included and referenced by “P.I. Station No. XX” in plan and elevation views. (P.I. refers to point of intersection). In rough terrain, broken lines representing side-hill profiles should be accurately plotted to assure final designs will provide for adequate conductor-to-ground clearances and pole heights. A drawing title block should be included. The block should identify the line and include the station numbers that are covered on the drawing sheet. The block should also include space for recording the names of personnel and the dates involved in various stages of drawing preparation, line design, checking, approval, and revisions.

Line design computer software may be used to import survey data and develop the land profile for the transmission line. Developments in surveying technologies have allowed the industry to go beyond the station-elevation-offset formats that have traditionally been used for transmission profile

FIGURE 10-1: SAMPLE OF A PLAN AND PROFILE


1"=200' HORIZONTAL
1"=20' VERTICAL
MD Rte. 222
Conservation Easement
County Park Entrance
Power Line
Distribution Crossing
25' Clearance Line
GUYING DETAIL-POLE 802
GUYING DETAIL-POLE 803
GUYING DETAIL-POLE 804
GUYING DETAIL-POLE 805
GUYING DETAIL-POLE 806
GUYING DETAIL-POLE 807
GUYING DETAIL-POLE 811
LEGEND:
TEMPORARY POLE NUMBER
EXISTING POLES
PROPOSED POLES
APPROX. WETLAND LOCATIONS
OLD POLE NUMBER
NEW POLE NUMBER
SILT FENCE
CONSTRUCTION MATS AND/OR GROUND MATS FOR WETLAND CROSSINGS
STABILIZED CONSTRUCTION ENTRANCE(SCE)
VIBRATION DAMPER MIN. 600' OF POLE
GENERAL NOTES:
1. WETLANDS AND BUFFERS ARE FLAGGED ON SITE THE REGIONAL LETTER OF AUTHORIZATION MUST BE ON SITE AND BEST MANAGEMENT PRACTICES AS LISTED IN THE REGIONAL LETTER OF AUTHORIZATION MUST BE FOLLOWED.
2. ALL POLES OTO HAVE A POLE GROUND ASSEMBLY TM-9-3R OR TM-9-3R-2 PLUS AS MANY ADDITONAL GROUND RODS (TM-9R) AS NEEDED.
3. ALL STRUCTURES WILL HAVE GROUND LINE POLE NUMBERS PER DRAWINGS TM-52-8, AND/OR TM-52-9.
4. ALL TANGENT POLES ARE TO BE FRAMED FOR FOCUS OPT-GW.
SAG NOTES
LOCATION | Wiestown Sub to Pole # 802 | Pole #802 to #803 | Pole #803 to #842
RULING SPAN | 89 ft. | 59 ft. | 501 ft.
CONDUCTOR | 556 ACSR "DOVE" 1117# @NESC HEAVY (350# @ 60°) | 556 ACSR "DOVE" 1411# @NESC HEAVY (350# @ 60°) | 556 ACSR "DOVE" 7896# @NESC HEAVY (4100# @ 60°)
G.W. | FOCUS OPT-GW 452 @NESC HEAVY (93# @ 60°) | FOCUS OPT-GW 486# @NESC HEAVY (93# @ 60°) | FOCUS OPT-GW 4623 @NESC HEAVY (2110# @ 60°)
I HEREBY CERTIFY THAT THIS DOCUMENT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MARYLAND.
SIGNED
DATE REG NO.
66KV TRANSMISSION LINE
NO | REVISION | DATE | BY | APP
2 | AS-BUILTS | 5/8/01 | TFS | JB
1 | ADDED SCE, WETLANDS | 4/5/00 | TTO
PROJECT
DRAWING NUMBER D-2858-1
SHEET 1 OF 8
BID SET APRIL 6, 2000
CIRCUIT 6741

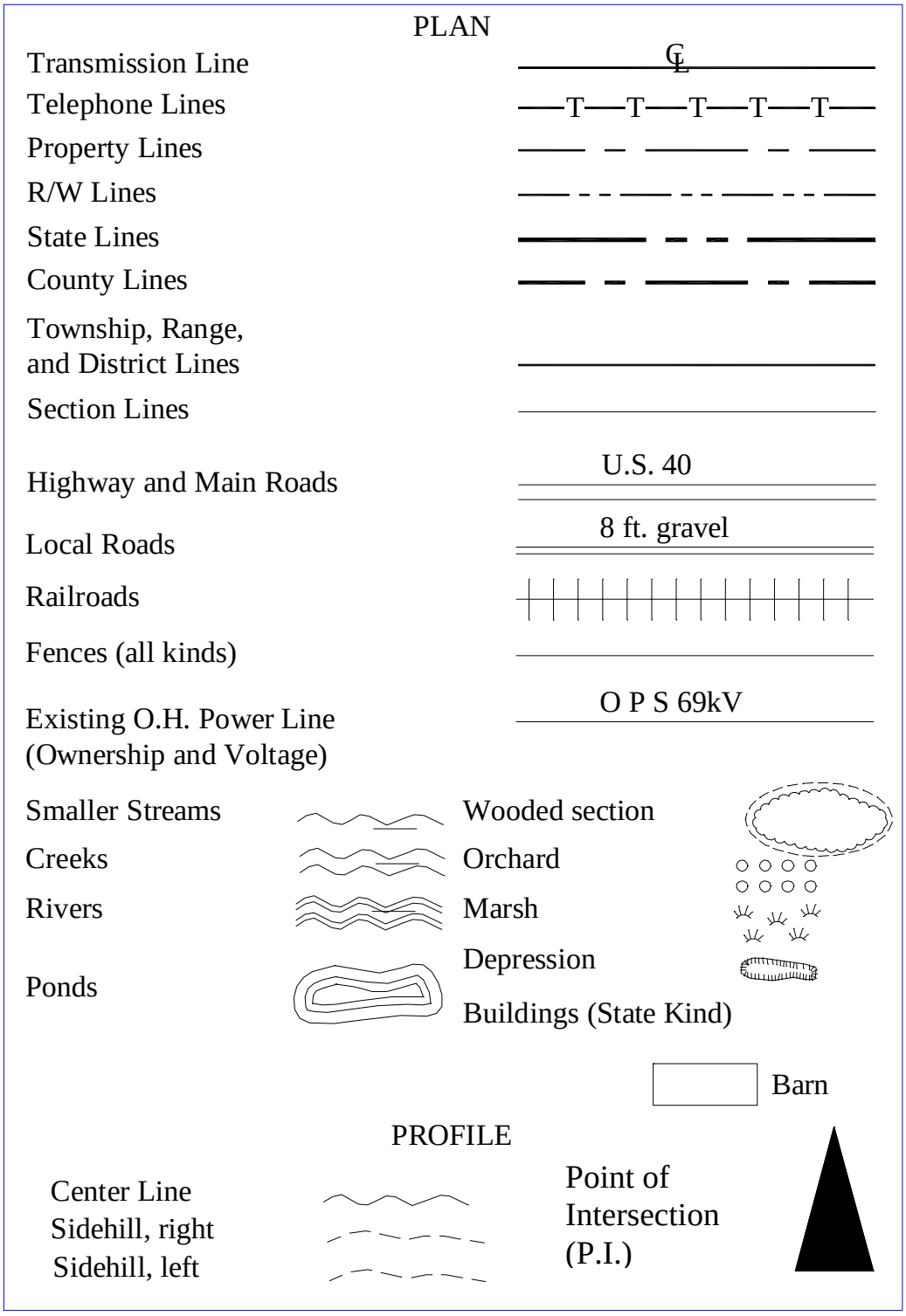


FIGURE 10-2: CONVENTIONAL SYMBOLS FOR PLAN-PROFILE

modeling. Use of three-dimensional Geographical Information System (GIS) modeling is becoming more common. Total station, geographical positioning system, photogrammetry, and electronic topographical maps (United States Geological Survey, USGS, maps) have been employed to collect data in electronic format and to develop quick and accurate terrain plan and profile for transmission lines.

Design software can use a three-dimensional survey format and develop profile drawings of the terrain along the centerline of the line. Some software can create interpolated points on profiles by creating a Triangular Irregular Network (TIN). The TIN can be used to develop a three-dimensional rendering of a transmission line.

Once the alignment and profile have been developed, computer programs are then used to spot structures along the profile. For an established family of structures, the computer can be used to automatically spot structures for the most economical line cost or the user may manually spot structures. Programs have been developed to automatically plot the sag curve of the conductor and to check insulator swing, structure strength, and clearances. A material list is often developed from computer generated plan-profile drawings.

Computer aided drafting and design software may provide all or part of the following:

- Importing survey data, to model terrain, and to create a profile;
- Modeling of structure, including strength, geometry, insulator swing and complete bill of material;
- Calculating conductor sag and tension;
- Locating structures (spotting) on the profile drawing;
- Calculating conductor stringing and sagging, at almost any temperature, to check design conditions such as uplift, ground clearance or insulator swing;
- Checking the line plan-profile against specific design criteria;
- Displaying the plan-profile or structure analysis in three dimensions; and
- Preparing reports and construction documents showing all construction material units on the plan and profile, as well as developing material reports, staking tables, offset clipping reports, etc.

Some design programs provide more custom drafting capabilities. Some are AutoCAD based; others are MICRO STATION based. Traditional methods used to spot structures can be as much as 70-80 percent more conservative than the computer aided design and drafting approach.

10.3 Sag Template: When computers are not used to spot structures and draw the conductor sag curve, manual techniques are used. Once the profile of the line has been drawn, the next step is to develop a sag template. The sag template is a scaling device used for structure spotting and for showing the vertical position of conductor (or ground wire) for specified design conditions . A sample conductor sag template is shown by Figure 10-3. The template is used on plan-profile drawings to graphically determine the location and height of supporting structures required to meet line design criteria for vertical clearances, insulator swing, and span limitations. The sag template permits alternate layout for portions of the line to be investigated and thereby aids in optimizing line design for economy.

Generally, the conductor sag curves control the line design. The sag template for the overhead ground wire is used to show the position of the wire in relationship to the conductors for special spans or change in conductor configuration. An uplift condition at the overhead ground wire may be checked by using the template cold curve.

10.3.1 Sag Template Curves: The sag template should include the following sag curves based on the design ruling span:

a. Hot (Maximum Sag) Curve: At maximum operating temperature, no ice, no wind, final sag curve, the hot curve is used to check for minimum vertical clearances. However, if the maximum sag occurs under an icing condition, this sag curve should be used for the sag template.

b. Cold Curve: At minimum temperature, no ice, no wind, initial sag curve, the cold curve is used to check for uplift and insulator swing.

c. Normal Curve: At 60°F, no ice, no wind, final sag curve, the normal curve is used to check normal clearances and insulator swing.

Sag curves are also used to locate the low point of sags and determine the vertical span lengths as illustrated by Figure 10-6. The curve intersection with the vertical axis line represents the low point position of sag.

Conductors of underbuild lines may be of different types or sizes than the transmission conductor. The hot curve of the lowest distribution conductor should be used for checking ground clearance. Cold curves may be required for each size of conductor to check for uplift or insulator swing.

10.3.2 Sag Template Design: Sag templates may be developed from information provided by the manufacturer of the conductor or from a graphical calculation method. Sag values needed to construct the template are available from the conductor manufacturer for a given conductor, ruling span, design condition and temperature. Sag values may also be determined using the graphic method referred to in Section 9.8 of Chapter 9. The template should be made to include spans three or four times as long as the normal level ground span to allow for spotting structures on steep terrain.

The form of the template is based on the fact that, at the time when the conductors are installed, horizontal tensions have to be equal in all level and inclined spans if the suspension insulators are plumb in profile. This is also approximately true at maximum temperature. To obtain values for plotting the sag curves, sag values for the ruling span are extended for spans shorter and longer than the ruling span. Generally for spans up to 1000 feet, it is sufficiently accurate to assume that the sag is proportional to the square of the spans (unless more accurate computed sag values are unavailable). The sag values used for the template may be determined as follows:

a. For the ruling span and its sag under each appropriate design condition and temperature, calculate other sags by the relationship:

$$S = \left(\frac{L}{RS}\right)^2 (S_{RS}) \qquad \text{Eq. 10-1}$$

where:

S = sag of other span in ft.
S_{RS} = sag of ruling span in ft.
L = length of other span in ft.
RS = ruling span sag in ft.

b. Apply catenary sag correction for long spans having large sags.

The template should be cut to include a minimum of one foot additional clearance than given in Table 4-1 (Chapter 4), to account for possible minor shifts in structure location and error in the plotted profile. Where the terrain or the surveying method used in obtaining ground profile is subject to greater unknowns or tolerances, the one foot additional clearance should be increased. The vertical offset between the upper two maximum temperature (hot) curves is equal to the total required clearance, including the specified additional clearance. It is shown as dimension "C" in Figures 10-3 and 10-4. The minimum temperature and the 60°F curves may be placed in any convenient location on the template.

A sag template drawing similar to Figure 10-3, made to the same scales as the plan-profile sheets, should be prepared as a guide for cutting the template. This template is made for a specified conductor, ruling span, and loading condition. A new template should be prepared for each line where there is any variation in voltage, conductor size, loading condition, design tension, or ruling span. A change in any one of these factors may affect the design characteristics of the template.

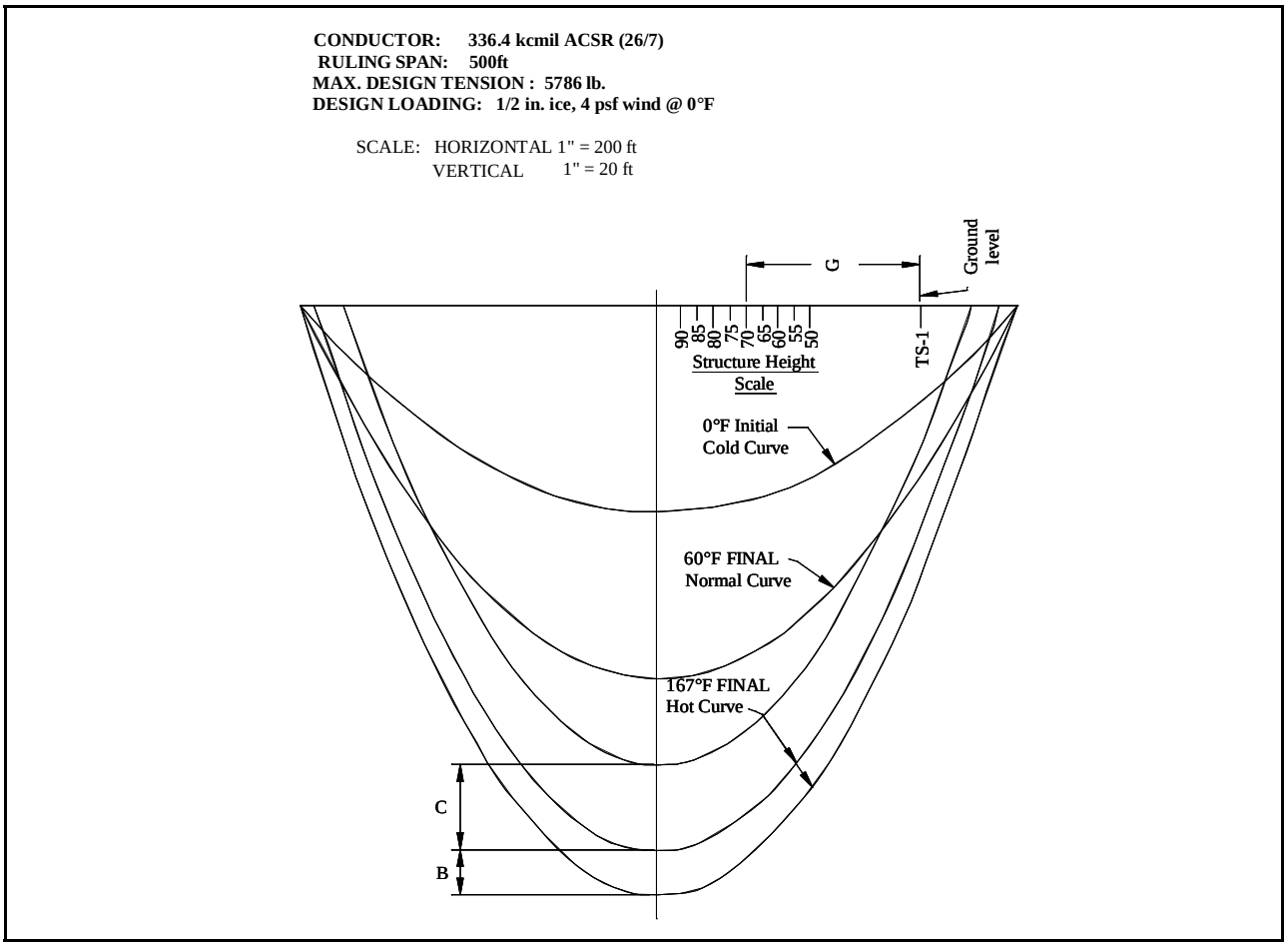


FIGURE 10-3: SPECIMEN SAG TEMPLATE FOR CONDUCTOR
(Reduced size, not to scale)
B = Sag for the level ground span, C = Total Ground Clearance,
G = Dimension from ground to point of attachment of lowest conductor

10.3.3 Sag Template Construction: The sag template should be made of dimensionally-stable transparent plastic material. A contrasting colored material (for example, red) is very helpful when the template is used to check plan-profile blueprint drawings.

Curves are first plotted on paper using the correct scales and then reproduced or copied on the plastic material. To cut a template, the transparent material is fastened securely over the curves drawn on paper and the centerline and upper curves are etched lightly by a sharp-pointed steel scriber. The outside edges of the template should be etched deeply so that the template can be easily broken out and the edges sanded smooth. Structure height scales may also be drawn or etched on the sag template, or a separate template, for determining the pole height required for each type of structure used. Etched lines should be filled with ink to make them easier to see when the template is used.

Conductor size, design tension and loading condition as well as ruling span and descriptive data for each curve should be shown on the template.

10.4 Structure Spotting

10.4.1 General: Structure spotting is the design process which determines the height, location, and type of consecutive structures on the plan-profile sheets. Actual economy and safety of the transmission line depends on how well this final step in the design is performed. Structure spotting should closely conform to the design criteria established for the line. Constraints on structure locations and other physical limitations encountered may prevent spotting of structures at optimum locations. Success of the effort to minimize or overcome these special conditions can be judged by how closely the final line layout follows the original design parameters.

Desired objectives of a well-designed and economical line layout are:

a. Spans should be approximately uniform in length, equal to or slightly less than the design ruling span. Generally, differential conductor tensions are minimized and may be ignored if adjacent span lengths are kept below a ratio of 1.5 to 1.

b. Maximum use should be made of the basic structure of equal height and type. The basic structure is the pole height and class which has been selected as the most economical structure for the given design condition.

c. The shape of the running conductor profile, also referred to as the grading of the line, should be smooth. If the conductor attachment points at the structures lie in a smooth-flowing curve, the loadings are equalized on successive structures.

For a generally level and straight line, with few constraints on structure locations, there is no conflict between these objectives. They can be readily achieved. Greater skill and effort are needed for lines with abrupt or undulating ground profile and for those where constraints on structure location exist. For example, there may be high or low points in the profile or features such as line angle points, crossings over highway, railroad, water, power and telecommunication lines, and ground with poor soil conditions. Structure locations and heights are often controlled or fixed by these special considerations. Alternative layouts between fixed locations may then be required to determine the best arrangement based on factors of cost and effective design.

10.4.2 Design Factors for Structure Spotting: The following design factors are involved in structure spotting and are covered in the identified chapters of this bulletin:

a. Vertical Clearances (Chapter 4)
- Basic, level ground
- Crossings
- Side hill
- Underbuild

b. Horizontal Clearances
- For insulator side swing condition (Chapter 7)
- To edge of right-of-way, vertical obstructions and steep side hills (Chapter 5)

c. Uplift (Chapter 12)

d. Horizontal or Vertical Span Limitations Due to:
- Vertical sag - clearance requirement (Chapters 4, 6)
- Conductor separation (Chapter 6)
- Galloping (Chapter 6)
- Structure strength (Chapters 13, 14)
- Crossarm strength (Chapter 13)

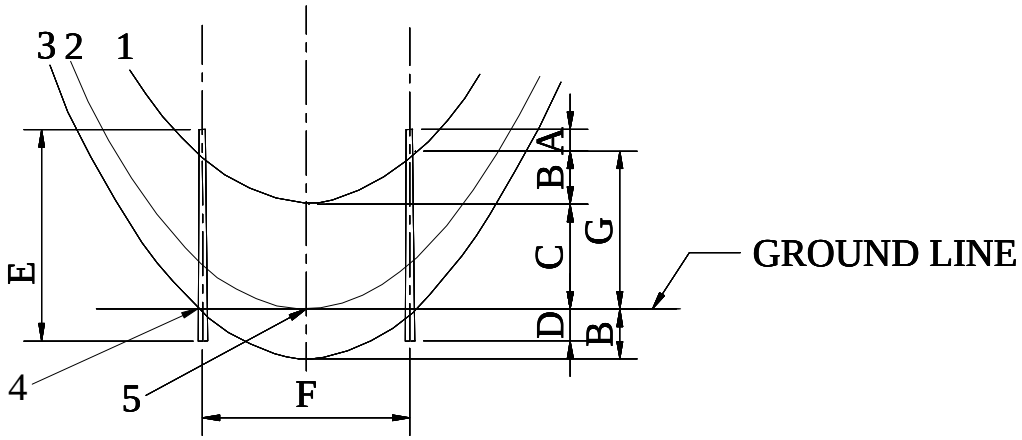
e. Angle and Deadend (Chapter 14)
- Guying arrangements
- Guy anchors

10.4.3 Preparation: The following are necessary for structure spotting:

- Plan-profile drawings of the transmission line,
- Sag template of the same scale as the plan-profile prepared for the design temperatures, loading condition, and ruling span of the specified conductor and overhead ground wire,
- Table of minimum conductor clearances over ground features and other overhead lines (Chapter 4),
- Insulator swing charts (Chapter 7),
- Horizontal and vertical span limitations due to clearance or strength requirements (Chapters 8, 9, and 13), and
- Guy arrangement and anchor requirements for angle and deadend structures (Chapter 14).

A height scale prepared for each structure type will aid in structure height determination. Supporting calculations should be summarized in chart or tabular form to facilitate application during structure spotting. This is especially advisable for the standard suspension structure which has a greater range of pole height and class, as well as bracing variations for H-frame structures. Selection of the proper pole may be affected by various criteria, such as span-controlled-by-clearance or span-limited-by-pole-strength, for a given pole height and class or bracing.

10.4.4 Process of Spotting: The process of spotting begins at a known or established conductor attachment point such as a substation take-off structure. For level terrain, the profile is essentially a straight line. When a sag template is held vertically and the ground clearance curve is held tangent to the ground profile, the edge of the template will intersect the ground line at points where structures of the basic height should be set. This relation is illustrated for a level span in Figure 10-4. Curve 1 (lowest conductor sag position) represents the actual sag of the conductor. Curve 2 (basic ground clearance curve) represents the actual position of the lowest conductor plus the required total ground clearance, "C."



Hot Curves (Maximum Sag)

Curve 1 - Lowest Conductor Sag Position
Curve 2 - Basic Ground Clearance Curve
Curve 3 - Edge of Template or Reference Line
Point 4 - Intersection Locates Pole of Basic Height
Point 5 - Tangent to Ground Profile

A = Dimension from top of pole to point of attachment of lowest conductor.-
B = Sag in level ground span.
C = Total ground clearance.
D = Setting depth of pole
E = Length of pole.

F = Level ground span.
G = Dimension from ground to point of attachment of lowest conductor

FIGURE 10-4: APPLICATION OF SAG TEMPLATE - LEVEL GROUND SPAN

The point where Curve 3 intersects the ground line determines the location of the next structure. This new location is found by drawing an arc along the edge of the template from Point 4 to the next point where Curve 3 intersects the ground line. The template should then be shifted and adjusted so that with the opposite edge of the template held on the conductor attachment point previously located with the clearance curve again barely touching the profile. The process is repeated to establish the location of each succeeding structure. After all structures are located, the structures and lowest conductor should be drawn in.

The above procedure can be followed only on lines that are approximately straight and which cross relatively flat terrain with the basic ground clearances. When line angles, broken terrain, and crossings are encountered, it may be necessary to try several different arrangements of structure locations and heights at increased clearances to determine the arrangement that is most satisfactory. Special considerations often fix or limit the structure locations. It is advisable to examine the profile for several span lengths ahead, take note of these conditions and adjust the structure spotting accordingly. Sometimes, a more balanced arrangement of span lengths is achieved by moving ahead to a fixed location and working back.

The relationship between the ground clearance and conductor curves is also used for spans other than level-ground spans. This is done by shifting the sag template until ground profile touches or is below the clearance curve with the previously established conductor attachment point is positioned on the conductor curve. The conductor curve would then indicate the required conductor height for any selected span. Structure height may be determined by scaling or by use of the proper structure height template, taking into account the change in the embedded pole length for poles other than the basic pole. Design limitations due to clearance or structure strength should be observed.

10.4.5 Crossings: For spans-crossing features such as highway and power lines, with different clearance requirements than the normal clearance, the ground clearance curve should be adjusted accordingly. In California, adequate ground clearance has to be maintained over all railroads, major highways, major telecommunication and power lines when a broken conductor condition in either of the spans adjacent to the crossing span. Other states are governed by the NESC, which does not require the broken conductor condition. The increase in sag due to a broken conductor in an adjacent span is usually significant only where suspension-type structures are used at crossings and for voltage at 230 kV or above. For tension structures, and for suspension structures at lower voltages, the sag increase normally will not seriously affect the clearance.

10.4.6 Insulator Side Swing - Vertical Span: Horizontal conductor clearances to supporting structures are reduced by insulator side swing under transverse wind pressure. This condition occurs where the conductor is supported by suspension-type insulators. Conductors supported by pin-type, post, or tension insulators are not affected and horizontal clearance of the deflected conductor position within the span becomes the controlling factor (see Chapter 5 of this bulletin). Suspension insulators also deflect laterally at line angle locations due to the transverse component of conductor tension.

Chapter 7 covers the preparation of insulator swing charts. At each structure location the charts are used to determine if insulator swing is within the allowed limit for the vertical and horizontal spans and line angle conditions. For suspension insulators supported on horizontal crossarms, a minimum vertical span has to be maintained to avoid excessive side swing. To maintain adequate clearance for insulators attached directly to the pole, and for some types of angle structures, the vertical span cannot exceed a maximum value (as indicated by the insulator swing chart). See Figure 7-5 of this bulletin for an example swing angle chart for the TH-233 large angle structure.

The vertical span is the distance between the conductor low points in spans adjacent to the structure. The horizontal span is the average value of the two adjacent spans to a structure. Where conductor attachments are at different elevations on adjacent structures, the low point is not at mid-span and will shift its position as the temperature changes. This shift can be readily seen by comparing the low point for the hot curve with its position for the cold curve. The vertical span value used to check the insulator swing should be based on the low point position which yields the most critical condition for the structure type. (See Chapter 7 for details on insulator swing)

Where minimum vertical span or uplift is the concern, the cold curve should be used. The normal temperature is more critical and should be used if the vertical span is limited by a maximum value. Figure 10-6 shows some examples of the relationship of conductor low points and vertical spans which may occur in a line profile.

If insulator swing is unacceptable, one of the following corrective steps, in order of preference, is recommended:

a. Relocate structures to adjust horizontal-vertical span ratio;
b. Increase structure height or lower adjacent structures;
c. Use a different structure, one with greater allowable swing angle or a deadend structure; or
d. Add weight at insulators to provide the needed vertical force.

10.4.7 Uplift: Uplift is defined as negative vertical span and is determined by the same procedure as vertical span. On steeply inclined spans when the cold sag curve shows the low point to be above the lower support structure, the conductors in the uphill span exert upward forces on the lower structure. The amount of this force at each attachment point is related to the

weight of the loaded conductor from the lower support to the low point of sag. Uplift exists at a structure (see Structure No. 4 in Figure 10-6) when the total vertical span from the ahead and back spans is negative. Uplift has to be avoided for suspension, pin-type, and post insulator construction. For structures with suspension insulators, the check for allowable insulator swing is usually the controlling criteria on vertical span. A rapid method to check for uplift is shown by Figure 10-5. There is no danger of uplift if the cold curve passes below the point of conductor support on a given structure with the curve on the point of conductor support at the two adjacent structures.

Designing for uplift, or minimizing its effects, is similar to the corrective measures listed for excessive insulator swing, except that adding of excessive weights should be avoided. Double deadends and certain angle structures can have uplift as long as the total force of uplift does not approach the structure weight. If it does, hold-down guys are necessary.

Care should be exercised to avoid locating structures that result in poor line grading (see Paragraph 10.1.4a of this chapter).

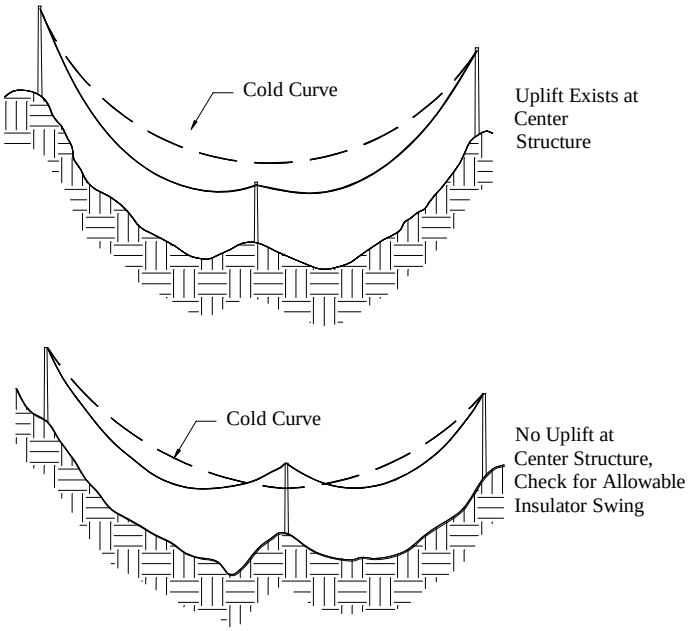

Cold Curve
Uplift Exists at Center Structure
Cold Curve
No Uplift at Center Structure, Check for Allowable Insulator Swing

FIGURE 10-5: CHECK FOR UPLIFT

10.4.8 <u>Other Considerations</u>: If maximum conductor tension or other limits are not exceeded, it may be preferable to use one long span with adequate conductor separation over a depression in the profile rather than use two short spans with a deadend structure at the bottom of the depression. A structure at the bottom of the depression may be subjected to considerable uplift at minimum conductor temperature. Also, poorer soil foundation conditions usually exist in the depression.

Care has to be exercised at locations where the profile falls sharply away from the structure to see that the maximum allowable vertical span as limited by the strength of the crossarm or insulator is not exceeded. Structure No. 2 in Figure 10-6 illustrates this condition. For maximum accuracy in the heavy or medium loading zone, the vertical span for this purpose should be determined with a curve made for the sag under ice load, no wind, at 32°F. For most conductors, however, the maximum temperature final sag curve will closely approximate the

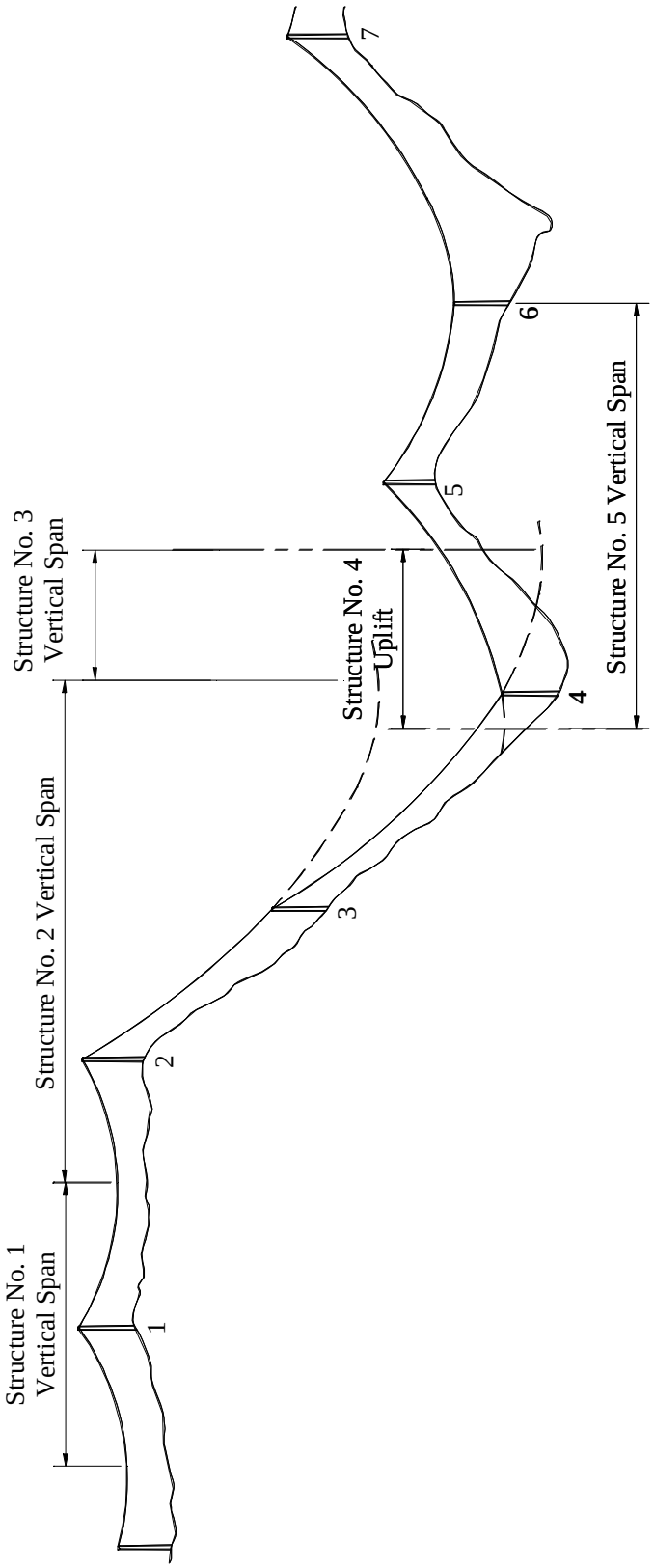


Figure 10-6 Sag Low Point, Vertical Spans and Uplift

curve for the ice-loaded conductor, and it may be used when checking for maximum vertical span. For guyed structures, the maximum vertical loads added to the vertical components from guy loads should be checked against the buckling strength of the pole

The profile in rough country where side hills are encountered should be prepared so that the actual clearances under the uphill and downhill conductor may be checked. For some long spans it may be necessary to check side hill clearance with the conductors in their maximum transverse swing position. H-frame type structures installed on side hills may require different pole heights to keep the crossarm level or one pole may be set a greater than normal setting depth.

Structures with adequate longitudinal strength (guyed deadends usually) are required at locations where longitudinal loading results from unequal line tensions in adjacent spans. For lines subject to heavy ice and high wind conditions and with long, uninterrupted section of standard suspension structures, consideration should be given to include some structures with in-line guys or other means to contain and prevent progressive, cascading-type failure. This is especially important for H-frame type structures with lower strength in the longitudinal direction when compared with its transverse strength. Measures to prevent cascading failures are also important for lines without overhead ground wire which tends to restrain the structure from collapsing longitudinally. A maximum interval of 5 to 10 miles is suggested between structures with adequate longitudinal capacity (guyed deadends usually), depending on the importance of the line and the degree of reliability sought.

10.5 Other Design Data: Conductor and ground wire sizes, design tensions, ruling span, and the design loading condition should be shown on the first sheet of the plan-profile drawings. For completeness, it is preferable that these design data be shown on all sheets. A copy of the sag template reproduced on the first sheet could serve as a record of design in case the template is misplaced or lost. Design data for underbuild and portions of the line where a change in design parameters occurs should similarly be indicated. The actual ruling spans between deadends should be calculated and noted on the sheets. This serves as a check that the actual ruling span has not deviated greatly from the design ruling span. The significance of this deviation is also covered in the ruling span section of Chapter 9. Where spans are spotted at lengths less than one-half or over twice the ruling span, deadending may be required.

As conductor sags and structures are spotted on each profile sheet, the structure locations are marked on the plan view and examined to insure that the locations are satisfactory and do not conflict with existing features or obstructions. To facilitate preparation of a structure list and the tabulation of the number of construction units, the following items, where required, should be indicated at each structure station in the profile view:

- Structure type designation,
- Pole height and class,
- Pole top, crossarm, and brace assemblies,
- Pole grounding units,
- Miscellaneous hardware units (vibration dampers at span locations), and
- Guying assemblies and anchors.

The required number of units or items required should be shown in parenthesis if greater than one. Successive plan-profile sheets should overlap. For continuity, and to avoid duplicate count, the end structure on a sheet should be shown as a broken line on the following sheet. The number and type of guying assemblies and guy anchors required at angle or deadend locations, based on guying calculations or application charts, should also be indicated. Design check, line construction, and inspection are facilitated if an enlarged guying arrangement, showing attachments and leads in plan and elevation, is added on the plan-profile sheet adjacent to each

guyed structure. Any special notes or large-scale diagrams necessary to guide the construction should be inserted on the plan-profile sheet. This is important at locations where changes in line design or construction occur, such as a slack span adjacent to a substation, line transposition, or change in transmission and underbuild circuits.

10.6 Drawing Check and Review: The completed plan-profile drawings should be checked to ensure that:

- The line meets the design requirements and criteria originally specified,
- Adequate clearances and computed limitations have been maintained, and
- Required strength capacities have been satisfied.

The sheets should be checked for accuracy, completeness, and clarity. Figure 10-7 is a Sample Check List for review of plan and profile sheets.

Profile: _____	***Date: _____***
Line: _____	***Voltage: _____***
Plan and Profile Drawing Nos._____	***Checked by: _____***
Loadings ***NESC District _____*** ***50 yr extreme wind(psf) _____*** ***Extreme ice load (radial inches)_____***	***Ruling Span: _____***
Conductor: _____	***Design Tension: _____***
OHGW: _____	***Design Tension: _____***
Underbuild: _____	***Design Tension: _____***

Sheet Number														
PLAN														
Property Information														
Swamps, Rivers, Lakes, etc.														
R/W Data, Boundaries														
Location of Buildings, Schools, etc.														
Other Utilities														
Obstructions, Hazards														
Roads														
Angles, P.I., Bearing of Centerline														
PROFILE														
Horizontal Span Length														
Vertical Span Length														
Type Structure														
Pole Strength														
Pole Height														
Pole Foundation Stability														
Crossarm Strength														
Conductor Clearance:														
To Ground or Side Hill														
To Support and Guys														
To Buildings														
Crossing														
Conductor Separation														
Conductor Tension Limitations														
Climbing or Working Space														
Guy Tension														
Guy Lead and Height														
Anchors														
Insulator Swing or Uplift														
Tap Off, Switches, Substations														
Underbuild														
Code Requirements														

FIGURE 10-7: SAMPLE CHECK LIST FOR REVIEW OF PLAN AND PROFILE

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11. LOADINGS AND LOAD FACTORS

11.1 General: The strength to be designed into a transmission line depends to a large extent on wind and ice loads that may be imposed on the conductor, overhead ground wire and supporting structure. These loadings are related generally to the geographical location of the line.

When selecting appropriate design loads, the engineer should evaluate climatic conditions, previous line operation experience and the importance of the line to the system. Conservative load assumptions should be made for a transmission line which is the only tie to important load centers.

The 2007 NESC indicates that structure and component strength should take into account temporary loads. Temporary loads imposed on a structure or component may include lifting of equipment, stringing operations, or a worker on a structure or component. This design manual does not address temporary loads.

The alternate method in the 2007 NESC has not been included in this design manual. The alternate method will not be used after July 31, 2010.

11.2 Loads

11.2.1 NESC Loading Districts: The NESC divides the country into three weather or loading districts, as shown in Figure 11-1.

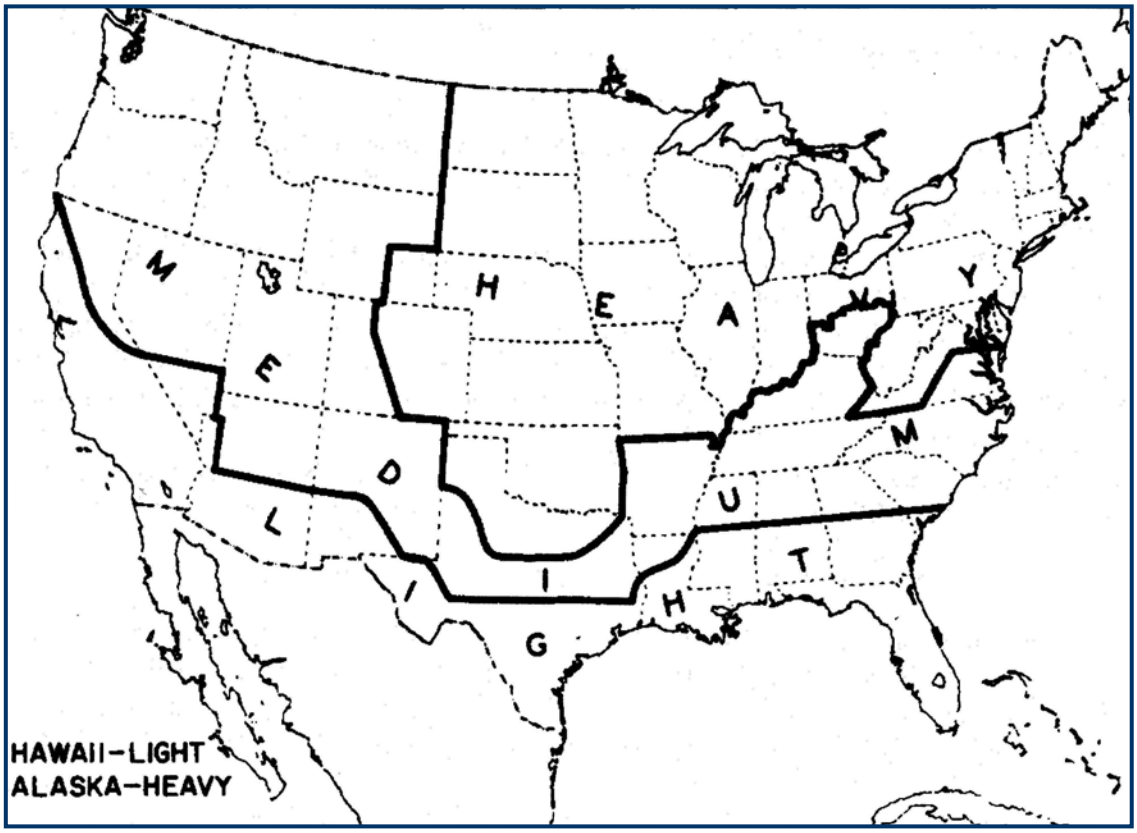

FIGURE 11-1: NESC LOADING DISTRICTS

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The minimum design conditions associated with each loading district are given in Table 11-1. Constants in this table are to be added to the vector resultant for tension calculations only.

TABLE 11-1
ICE, WIND, TEMPERATURE, AND CONSTANTS

NESC Loading		Design Temp. (F°)	Radial Ice Thickness (inches)	Wind Loading	Constants (lbs/ft)
Loading District	Heavy	0°	0.50	4 psf	0.30
	Medium	15°	0.25	4 psf	0.20
	Light	30°	0	9 psf	0.05
Extreme Wind		60°	0	See Figure 11-2	NA
Extreme Ice with Concurrent Wind		15°	See Figure 11-3	See Figure 11-3	NA

Designing to these minimum requirements may not be sufficient. Extreme winds and special ice conditions should be investigated. Determination of an appropriate design load to account for extreme winds is easier than determining a heavy ice design load. Meteorological data may be available on high winds, but little data is available on extreme ice loads. Heavy ice combined with a relatively high wind should also be considered.

11.2.2 Extreme Ice: In certain areas of the country heavy ice may be predominant. The engineer should review the experience of utilities or cooperatives in the area of the line concerning ice conditions. The number and frequency of outages in the area due to ice storms, and the design assumptions used for existing lines in the area should be examined. From this data, the engineer can reasonably decide if a heavy ice condition greater than what is required by the NESC needs to be included in the design.

If historical data on icing conditions is lacking, the engineer should consider designing the line for extreme wind conditions without ice, and for loading zone conditions. The engineer would then calculate the maximum ice load the structure could sustain without wind and evaluate this specific ice condition.

11.2.3 Extreme Winds: Although the NESC requires that structures over 60 ft. sustain high winds, Rural Utilities Programs recommends that all transmission lines meet extreme wind requirements. Required values for temperature and wind are listed in Table 11-1 and Figure 11-2. The NESC allows linear interpolation when considering locations between isotachs. Local meteorological data should also be evaluated in determining a design high wind speed. For wind speeds other than a 50 year recurrence interval, refer to Appendix E.

Equations in Tables 250-2 and 250-3 of the NESC have been incorporated in computer programs as part of the structure analysis. These equations are included in the definitions for the variables in Equations 11-1 and 11-2 of this bulletin. Tables 11-2, 11-3, 11-4 and 11-5 provide calculated values for the parameters in these equations.

Equation 11-1 should be used to calculate the load in the unit wind load on a circular **wire** in pounds per linear foot.

$$p = 0.00256 * V^2 * k_z * G_{RF} * d / 12 \qquad \text{Eq. 11-1}$$

- p = unit load per unit foot, lbs./ft.
- V = Basic Wind Speed, 3 –second gust wind speed in miles per hour at 33 ft. above ground with an annual probability of .02 (50 year return period), Figure 11-2
- k_Z = Velocity Pressure Exposure Coefficient, shown in Table 11-2 or by the equation: $k_z = 2.01(h/900)^{(2/9.5)}$ where h = height of the wire at the structure and is between 33 feet and 900 feet
- G_{RF} = Gust Response Factor, shown in Table 11-3 or by the equation: $G_{RF} = [1+(2.7E_w B_w^{0.5})]/k_v^2$ where $E_w = 0.346 (33/h)^{1/7}$ and $B_w = 1/(1+0.8L/220)$ $k_v = 1.43$ h = height of the wire at the structure L = design wind span (also known as HS)
- d = diameter of the conductor in inches

TABLE 11-2
WIRE VELOCITY PRESSURE EXPOSURE COEFFICIENT (k_Z)

Height of Wire(ft)	k_z
≤ 33	1.00
34 – 50	1.10
51 – 80	1.20
81 – 115	1.30
116 – 165	1.40

TABLE 11-3
WIRE GUST RESPONSE FACTOR, G_{RF}

Height of Wire At the Structure h (ft.)	Wire, G_{RF}, for Various Span Lengths in feet			
	251 - 500	501 - 750	751 - 1000	1001 -1500
≤33	0.86	0.79	0.75	0.73
34 – 50	0.82	0.76	0.72	0.70
51 – 80	0.80	0.75	0.71	0.69
81 – 115	0.78	0.73	0.70	0.68
116 – 165	0.77	0.72	0.69	0.67

TABLE 11-4
COMBINED FACTOR k_Z*G_{RF}
FOR COMMON WIRE HEIGHTS

Height of Wire At the Structure h (ft.)	Wire, G_{RF}, for Various Span Lengths in feet)			
	251 – 500	501 - 750	751 - 1000	1001 -1500
34 - 50	0.90	0.84	0.79	0.77
51 - 80	0.96	0.90	0.85	0.83
81 - 115	1.01	0.95	0.91	0.88

For simplicity, the designer may wish to use the height of wire to be the height to the overhead groundwire at the structure.

To calculate the wind load on a **structure** in pounds, equation 11-2 should be used.

$$P = .00256 * V^2 * k_z * G_{RF} * C_f * A \qquad \text{Eq. 11-2}$$

P = wind load in pounds

V = As defined for Equation 11-1

k_Z = Velocity Pressure Exposure Coefficient, shown in Table 11-5 or by the equation: $k_z = 2.01(0.67h/900)^{(2/9.5)}$ where h = height of the structure above groundline

G_{RF} = Gust Response Factor, shown in Table 11-5 or by the equation : $G_{RF} = [1+(2.7E_s B_s^{0.5})]/k_v^2$ where
$E_s = 0.346\ (33/(0.67\text{-}h)^{1/7}$ and
$B_s = 1/(1+0.8L/220)$
$k_v = 1.43$
h = height of the structure above groundline
L = design wind span (also known as HS)

C_f = drag coefficient

A = projected wind area in square feet

TABLE 11-5
STRUCTURE k_Z, G_{RF} , and COMBINED k_Z G_{RF} Factor

Height of Structure, ft	k_Z	G_{RF}	Combined 'k_Z G_{RF}' factor
≤ 33	0.92	1.02	0.94
34 – 50	1.00	0.97	0.97
51 – 80	1.10	0.93	1.02
81 – 115	1.20	0.89	1.07
116 – 165	1.30	0.86	1.12

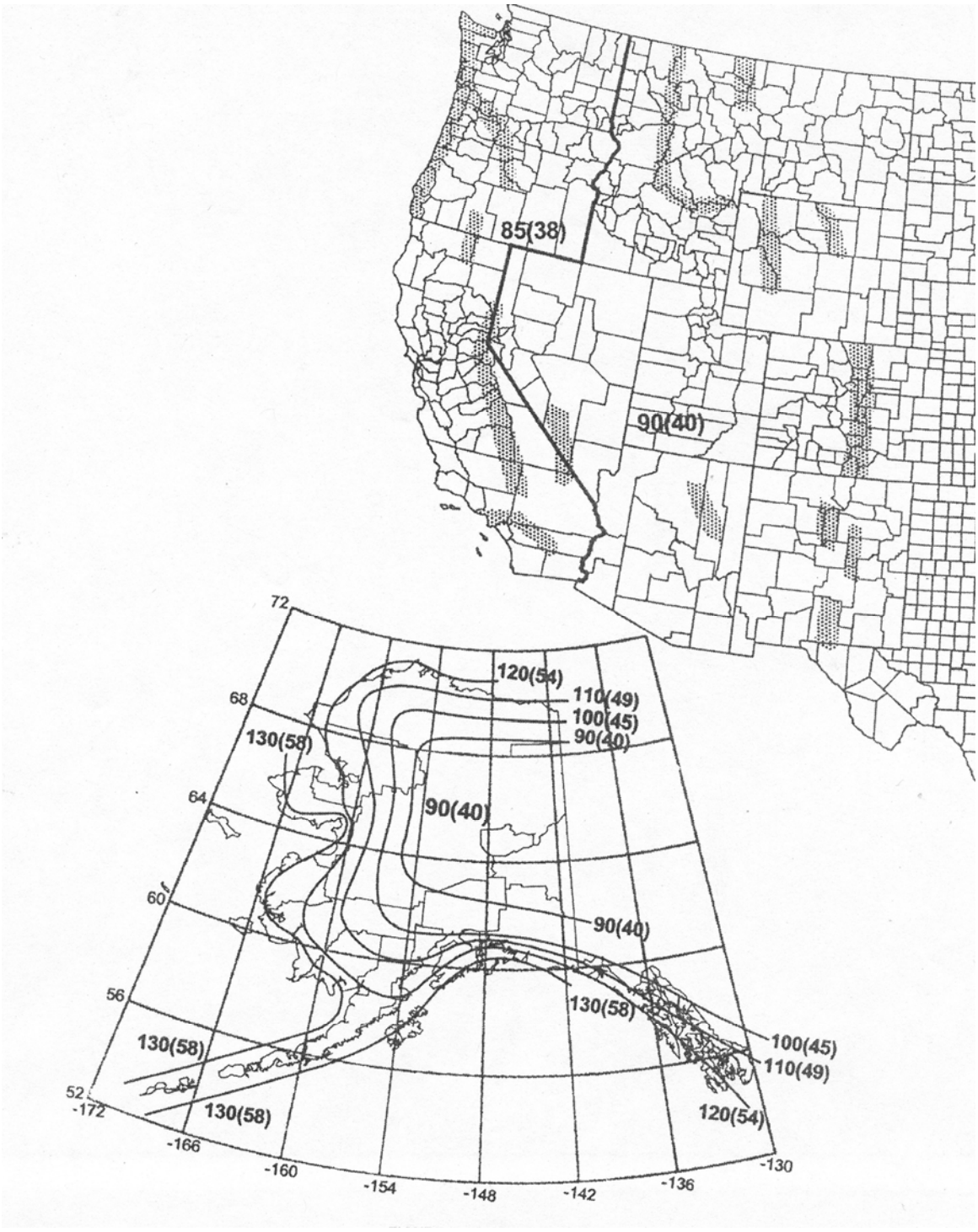

FIGURE 11-2a: EXTREME WIND SPEED IN MILES PER HOUR AT 33 FT. ABOVE GROUND (50-year mean recurrence interval)

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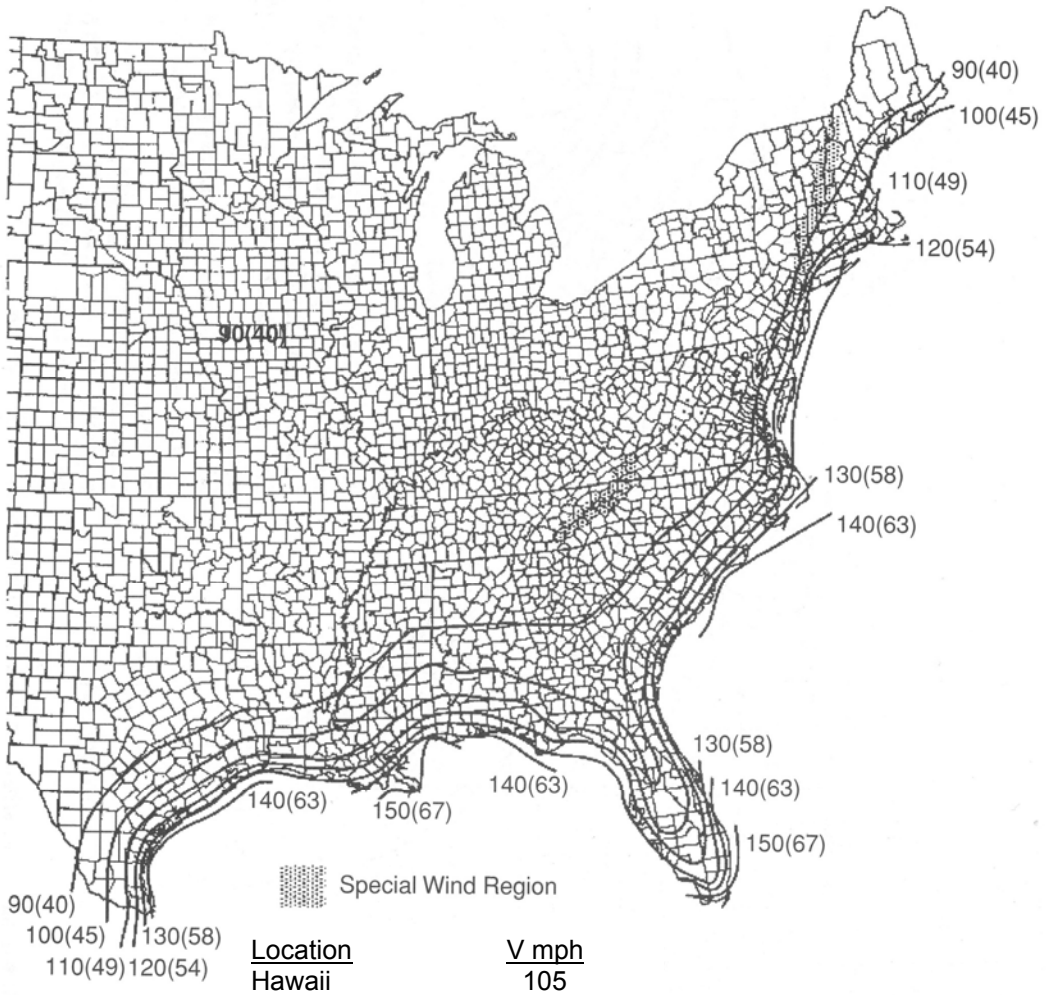

Location	V mph
Hawaii	105
Puerto Rico	145
Guam	170
Virgin Islands	145
American Samoa	125

Notes:

1. Values are nominal design 3-second gust wind speeds in miles per hour at 33 ft. above gound for Exposure C category.
2. Linear interpolation between wind contours is permitted.
3. Islands and coastal area outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.

FIGURE 11-2b: EXTREME WIND SPEED IN MILES PER HOUR
AT 33 FT. ABOVE GROUND
(50-year mean recurrence interval)

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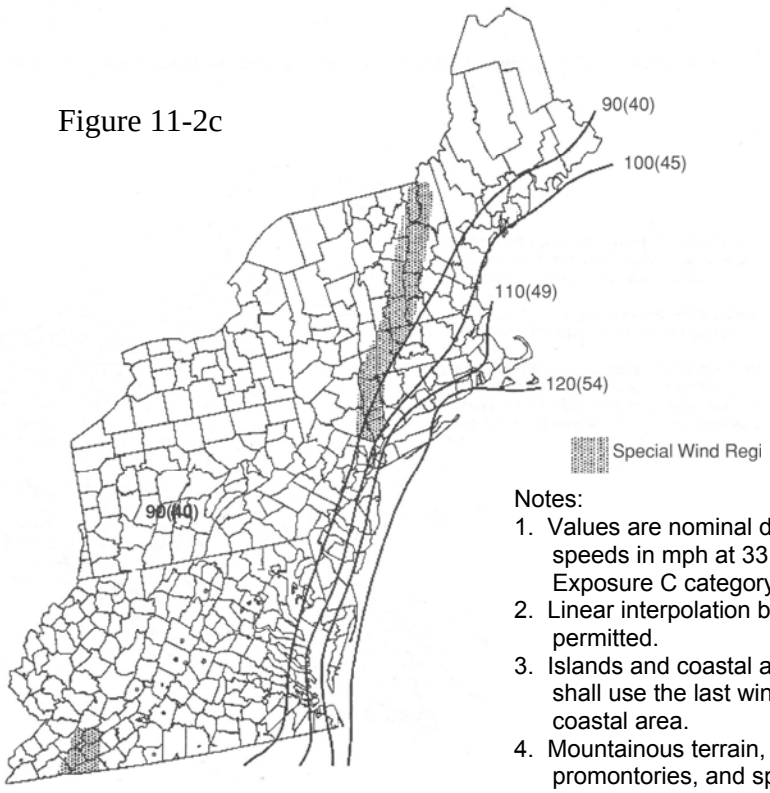
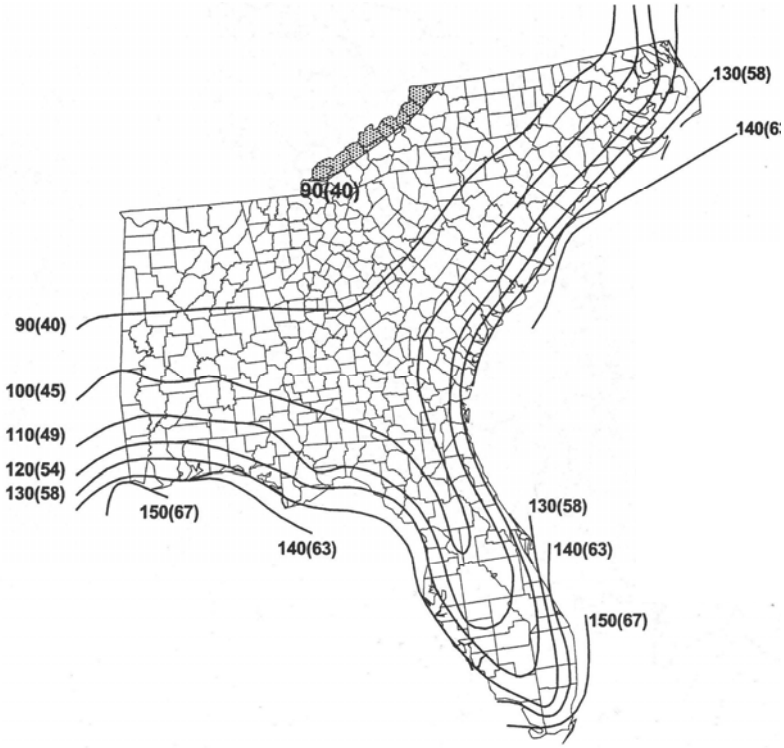
Figure 11-2c



Notes:
1. Values are nominal design 3-second gust wind speeds in mph at 33 ft above ground for Exposure C category.
2. Linear interpolation between wind contours is permitted.
3. Islands and coastal area outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.

Figure 11-2d



FIGURES 11-2c,11-2d: EXTREME WIND SPEED IN MILES PER HOUR AT 33 FT.ABOVE GROUND FOR THE NORTHEAST AND SOUTHEAST
(50-year mean recurrence interval)

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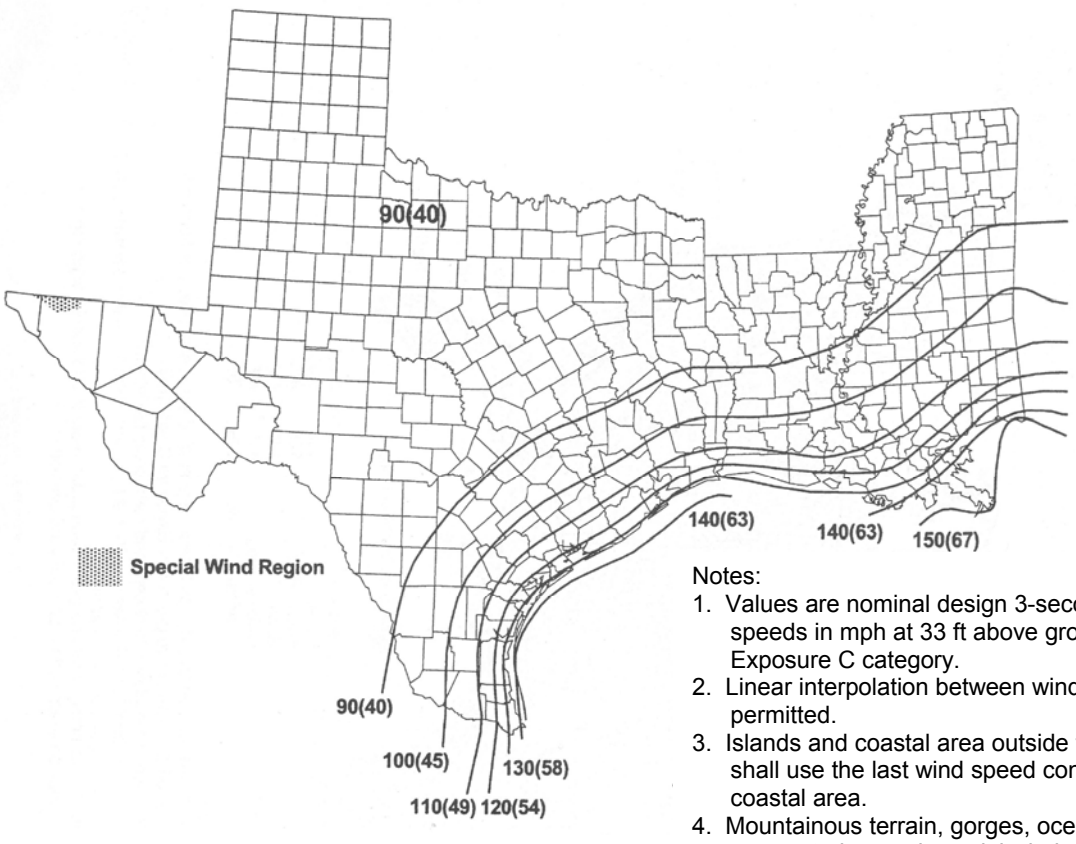
90(40)
140(63)
140(63)
150(67)
Special Wind Region
90(40)
100(45)
130(58)
110(49)
120(54)
Notes:
1. Values are nominal design 3-second gust wind speeds in mph at 33 ft above ground for Exposure C category.
2. Linear interpolation between wind contours is permitted.
3. Islands and coastal area outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.

FIGURES 11-2e: EXTREME WIND SPEED IN MILES PER HOUR AT 33 FT ABOVE GROUND FOR TEXAS, LOUISIANA AND MISSISSIPPI
(50-year mean recurrence interval)

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11.2.4 <u>Extreme Ice with Concurrent Wind Loads</u>: The NESC requires that structures over 60 ft. be designed to withstand the ice and wind loads associated with the Uniform Ice Thickness and Concurrent Wind Speed specified in NESC Figure 250-3 and in Figures 11-3a to 11-3d of this bulletin; however, it is recommended that all transmission lines meet these requirements. Required values for temperature, ice and wind are listed in Table 11-1.

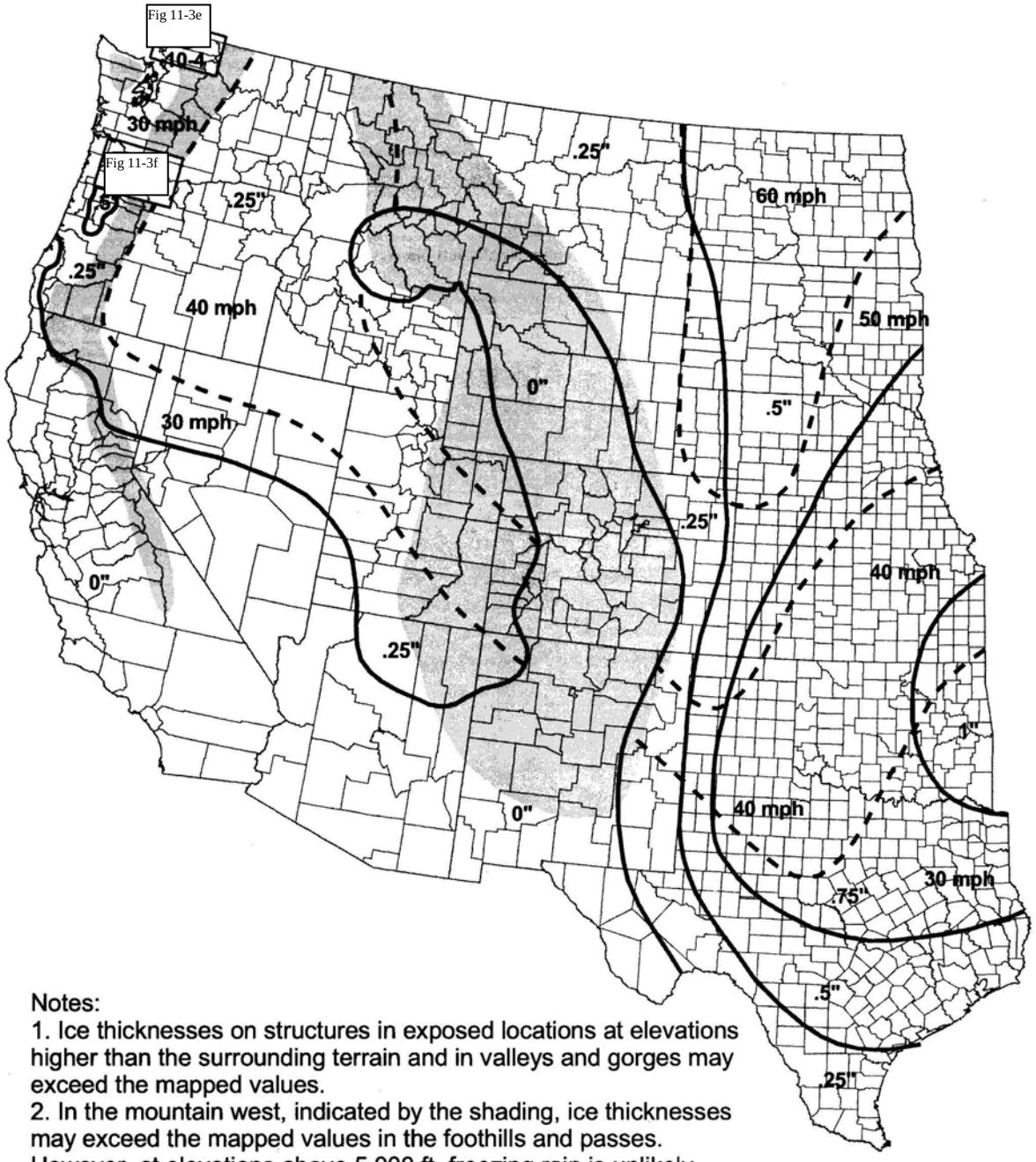

FIGURE 11-3a: UNIFORM ICE THICKNESS DUE TO FREEZING RAIN WITH CONCURRENT 3-SECOND GUST WIND SPEEDS (50 yr. mean recurrence)

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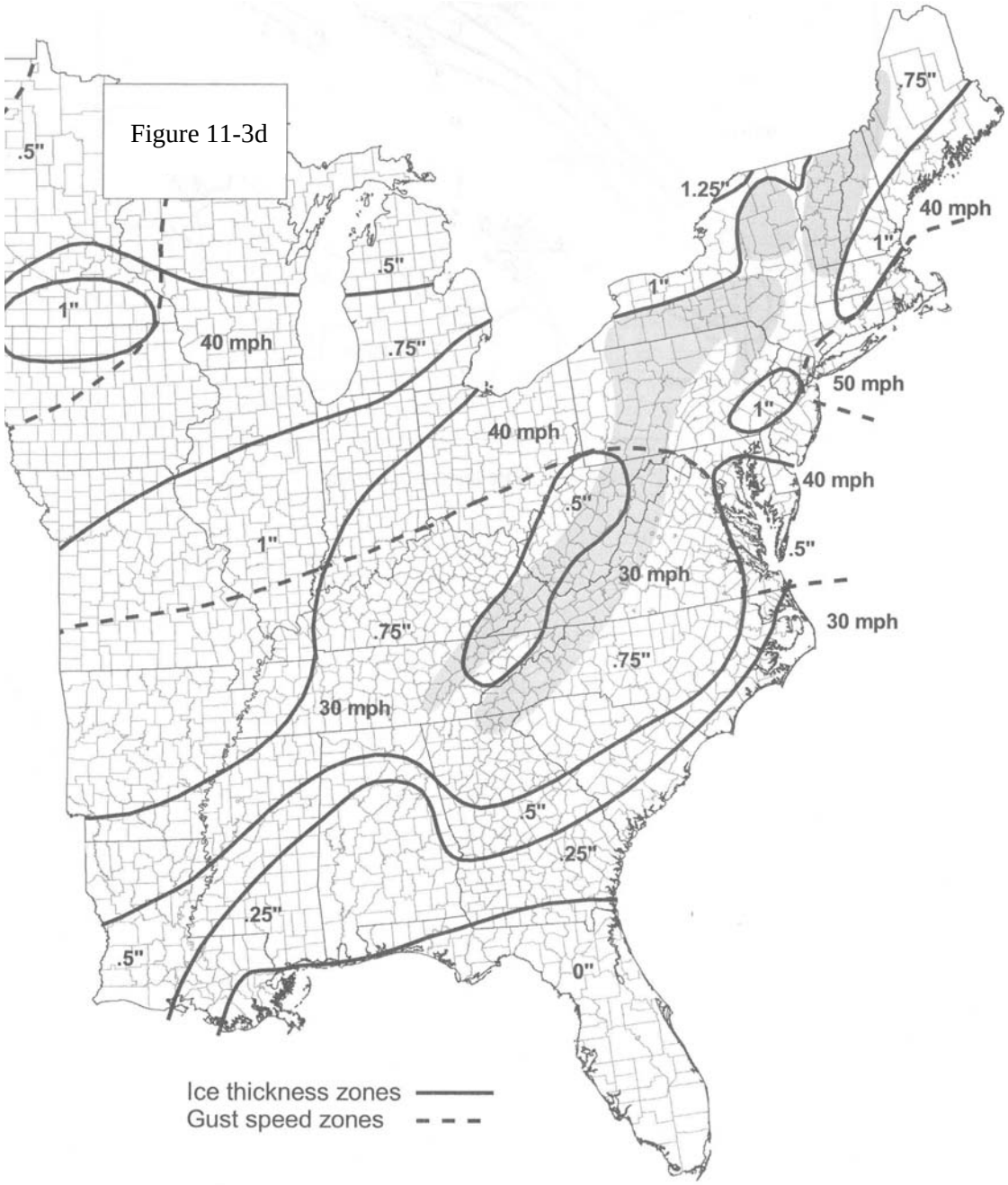

FIGURE 11-3b: UNIFORM ICE THICKNESS DUE TO FREEZING RAIN WITH CONCURRENT 3-SECOND GUST WIND SPEEDS (50 yr. mean recurrence)

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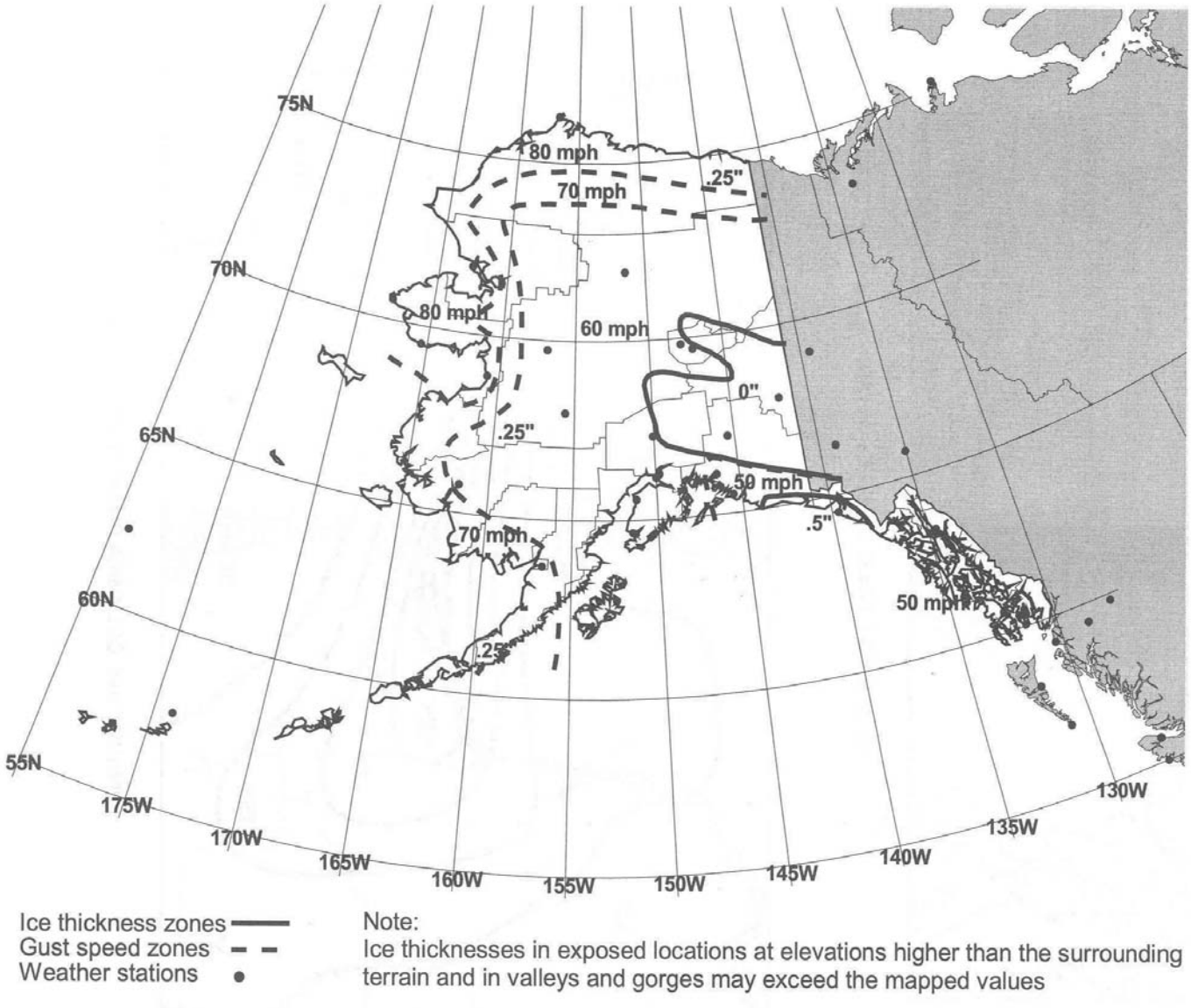

FIGURE 11-3c: UNIFORM ICE THICKNESS DUE TO FREEZING RAIN WITH CONCURRENT 3-SECOND GUST WIND SPEEDS FOR ALASKA
(50 year mean recurrence interval)

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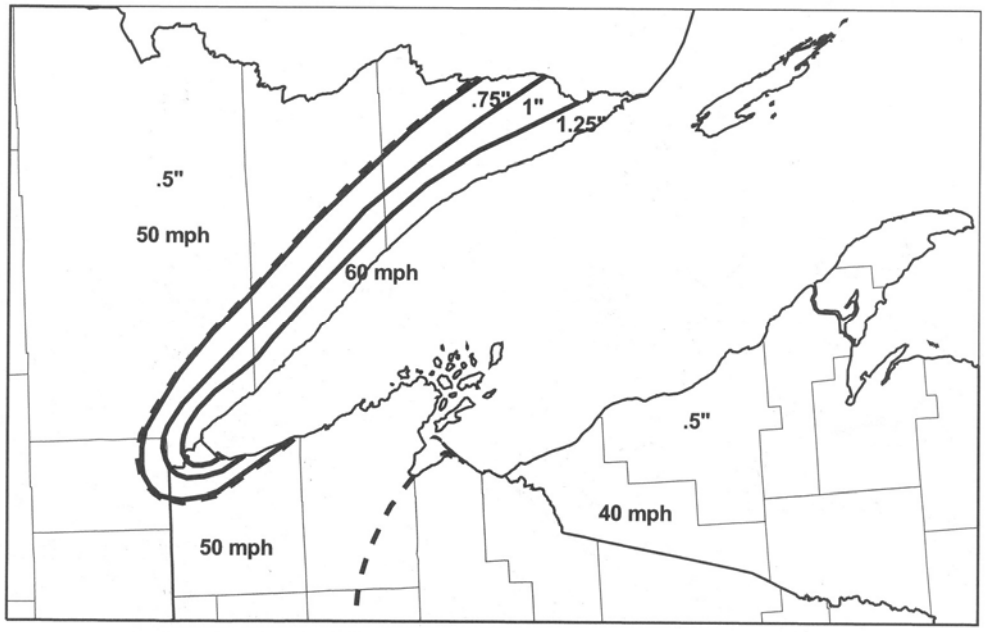

FIGURE 11-3d: UNIFORM ICE THICKNESS DUE TO FREEZING RAIN WITH CONCURRENT 3-SECOND GUST WIND SPEEDS FOR LAKE SUPERIOR (50 yr. mean recurrence)

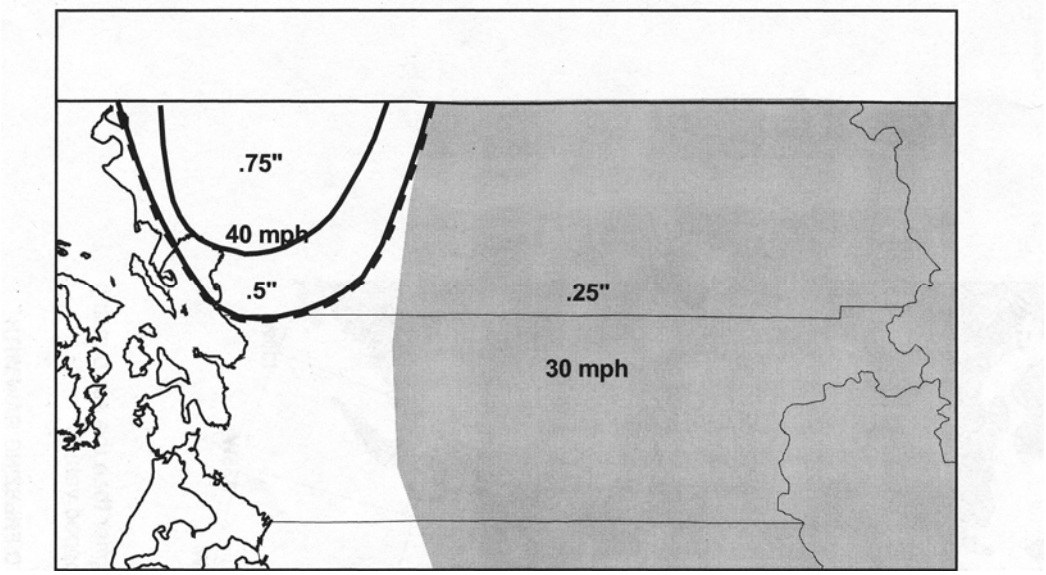

FIGURE 11-3e: UNIFORM ICE THICKNESS DUE TO FREEZING RAIN WITH CONCURRENT 3-SECOND GUST WIND SPEEDS FOR FRASER VALLEY DETAIL (50 yr. mean recurrence)

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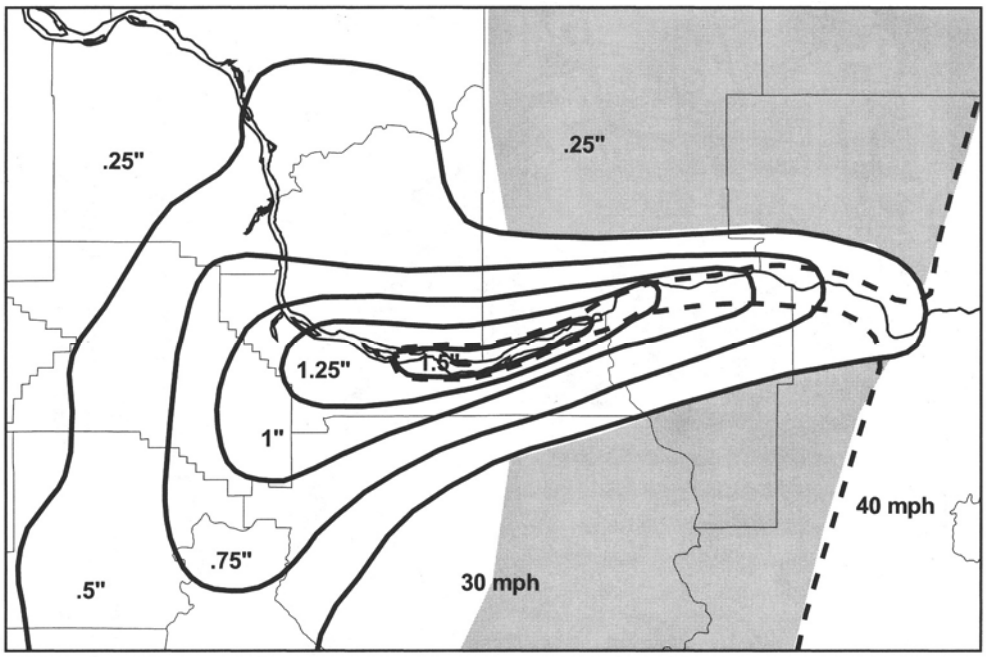

FIGURE 11-3f: UNIFORM ICE THICKNESS DUE TO FREEZING RAIN WITH CONCURRENT 3-SECOND GUST WIND SPEEDS FOR COLUMBIA RIVER GOUGE
(50 yr. mean recurrence)

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11.2.5 <u>Longitudinal Loads</u>: Unbalanced longitudinal loads on a line may occur because of:

- Unequal wind load and/or differential ice conditions on equal or unequal spans
- Construction and maintenance activities
- A broken wire
- Stringing loads
- A change in ruling span

Traditionally, standard tangent wood pole structures have not been designed for broken conductor longitudinal loads and have relied on the restraining capacity of deadends. The 2002 edition of the NESC recommends that structures having a longitudinal strength capability be provided at reasonable intervals along the line.

Several methods to reduce the risk of cascading transmission line structures due to broken wires have been recommended in the American Society of Civil Engineers (ASCE) Manual and Report on Engineering Practice No. 74 "Guidelines for Electrical Transmission Line Structural Loading," copyright 1991. They are summarized below.

<u>Method 1, Install "Stop" Structures at Specified Intervals:</u> This method consists of placing deadend structures, longitudinal guys, or regular tangent structures designed to resist deadend loads at intervals along the line to limit the number of cascading structures to a manageable number. This method is most practical for H-frames or narrow-based lattice towers which do not possess enough inherent longitudinal capacity to resist longitudinal loads. In these cases, stop structures are used because the cost to strengthen each structure to resist cascading may be high and the addition of guys at each structure may not be desirable.

Method 2, Install Release Mechanisms**:** Slip or release-type suspension clamps may be used as "fuses" to limit the longitudinal loads applied by broken wires. This is actually very similar to Method 1. The major difference between Method 1 and this Method is that "fuses" are used to minimize the unbalanced loads used to design each structure. The structures also have to be capable of withstanding construction and maintenance loads without endangering line crew personnel. Where heavy ice buildups are frequent, this could be an insurmountable problem. As such, this method is not recommended in areas of heavy ice, since unbalanced ice loads could result in unexpected failures.

Method 3, Design All Structures for Broken Wire Loads: Rigid lattice towers, guyed tangents (guyed in four directions) and single-shaft pole structures have an inherent longitudinal capacity. In many instances, such structures can be economically designed to resist longitudinal loads. The loads are typically based on the "residual static load" (RSL). The RSL is a load at a wire support after breaking one phase or a ground wire under every day conditions (no ice, no wind, 60ºF). Considerations in determining the RSL include insulator swing, structure deflection and suspension clamp slippage. Some designers have used 60 percent to 70 percent of the every day tension for conductors and 100 percent of the every day tension for ground wires. The suggested longitudinal loading consists of applying RSLs in one direction to a nominal one-third of conductor support points or to one (or both) ground wire support point(s). The suggested vertical loading consists of one-half or more of the vertical load(s) imposed by the broken wire(s) along with all of the vertical loads imposed by the other intact wires. Although every structure is designed to resist cascading, in the event of the catastrophic loss of a single structure, localized failures in adjacent structures should be expected.

A blend of Methods 2 and 3 would involve designing the main body of the structure (or pole) for slightly larger longitudinal loads than those used for the design of the support arms and/or ground wire peak. The idea is to limit the loads applied to the body of the structure (or pole) by "sacrificing" the arms or ground wire peak, thereby reducing the number of poles damaged from a broken wire event and decrease the likelihood of an unmanageable cascade. If such a event occurred, it could result in damage to several (perhaps numerous) support arms and/or ground wire peaks.

11.2.6 Example of Extreme Wind Calculations: A proposed 161 kV line using the TH-10 structure is expected to have spans ranging from 501 to 900 feet and to be composed of structures with wood poles 60 to 90 feet high. The line is expected to be located in northern Mississippi and will have a 795 26/7 ACSR conductor. Calculate the extreme wind load to be used in the design.

Extreme wind calculations are made for wind on the wires and wind on the structure. For wind on the wires, the engineer should calculate the wind on the overhead groundwires and the wind on the conductors. For wind on the overhead groundwires, a review of Table 11-4 indicates that 0.9 to 0.85 is to be used for the combined factor of **k_Z*G_{RF}'** for spans 501 to 1000 feet and for wire heights 52 feet to 79 feet above ground (for structures using 60 to 90 foot poles). The conductors on the TH-10 are located approximately 13 feet from the top of the pole. The height from the ground to the conductors at the structure will range from 39 to 63 feet above ground. . For wind on the conductors, review of Table 11-4 indicates that values of 0.9 to 0.79 may be used as the combined factor of '**k_Z*G_{RF}'** for spans 501 to 900 and for wire heights 39 to 63. (Poles are 52 feet to 79 feet above ground).

For wind on the structures, use Table 11-5. For structures of heights 52 to 79 feet above ground, Table 11-5 indicates that the combined '**k_Z*G_{RF}'** factor for the structure is 1.02.

Wind pressure (psf) on the overhead groundwires:

$p = 0.00256 * V^2 * k_z * G_{RF}$

$p = 0.00256 * 90^2 * 0.9$

p = 18.66 psf; use 19 psf in design

Wind pressure (psf) on the conductors:

$p = 0.00256 * V^2 * k_z * G_{RF}$

$p = 0.00256 * 90^2 * 0.9$

p = 18.66 psf; use 19 psf in design

Wind pressure (psf) on the structure:

$p = 0.00256 * V^2 * k_z * G_{RF}$

$p = 0.00256 * 90^2 * 1.02$

p = 21.15 psf; use 22 psf in design

For 21 psf, the unit trnasverse load on the conductor p_t = 1.9390 lbs/ft (Appendix B)
Therefore, for 19 psf, the unit load will be 1.7543 lbs/ft (or 1.9390x19/21)

11.2.7 Example of Extreme Ice/Wind Calculations:

Using the same example line in the previous paragraph (11.2.6), the line located in northern Mississppi has a combined ice and wind load of .75inch of ice and a 30 psf wind. Calculate the transverse and vertical unit loads on the conductor.

For the transverse unit load:
The diameter of the conductor including ice = 1.108 in (Appendix B) + (.75x2) = 2.608 in..
The unit wind load on the conductor p_t = 30 lbs/ft^2 x 2.608 inches/12in/ft x 1ft = 6.520 lbs/ft

For the vertical unit load:
The vertical unit load, w_c, is the dead weight of the conductor plus the ice load per foot of conductor = 1.0940 lbs/ft + [3.1416((1.108+(2x.75))^2 – (1.108)^2)/4/144 x 1 ft] x 57 lbs/ft^3 = 2.8269 lbs/ft

11.3 Load Factors for New Construction: Agency transmission lines are to be built to Grade B construction. In Table 11-6, the columns under the Rural Utilities Service headings give the recommended minimum load factors to be applied to the light, medium, and heavy loading districts of the NESC and also the recommended strength factors to be applied in the design of guys, anchors, crossarms, and structures.

Recommended load factors and strength factors to be applied to extreme wind loadings are in Table 11-7. The factors are intended to take into account approximations made in the design and analysis.

11.4 Application of Load Factors and Strength Factors: In the application of the load factors and strength factors, the objective is to design a structure with resistance greater than the maximum load expected during the lifetime of the structure and to design the structure with an acceptable level of safety and reliability. The use of load factors and strength factors can be expressed as follow:

$$ØR \geq (LF)Q \qquad \text{Eq. 11-3}$$

where:

R	=	measure of material strength or resistance
Ø	=	a strength factor, less than 1.0
Q	=	load
LF	=	load factor, greater than 1.0

'Ø' is a multiplier which limits the resistance, R, and accounts for the variability of the resistance property. '(LF)' is a multiplier that compensates for uncertainty in the load or assumptions made in the analysis. 'Ø' and '(LF)' may be based on statistics, past engineering judgment, past practice, or may be legislated.

The traditional view of a safety factor (or load factor) may be expressed as 'LF' divided by 'Ø'.

Tables 11-6 and 11-7 are based on the relationship defined in Equation 11-3. In previous editions of this bulletin, the method using the load factors was used. That method has been dropped from this bulletin.

11.4.1 Example Calculation Showing the Use of Strength and Load Factors:
A Douglas fir, 80 ft. tangent pole is to sustain a 750 lbs. transverse load two feet from the top. Assume this load is based on NESC heavy loading district loads. What class pole should be used for this construction? The pole is embedded 10 feet. The length of the moment arm used to calculate the induced moment at groundline is 68 feet.

In this case, R is the moment capacity of the pole at groundline and 'Q' is the horizontal load (750 lbs.). Using the strength factors (Ø) and load factors (LF) from Table 11-6, Equation 11-3 becomes:

$$ØR \geq (LF)Q$$

$$0.65M_{\text{Moment capacity at the groundline}} \geq 2.50(750 \text{ lbs})(68 \text{ feet})$$

$$M_{\text{Moment capacity at the groundline}} \geq 196{,}154 \text{ ft.-lbs}$$

The pole should have a moment capacity of 196 ft-kips at the groundline. A class 3 Douglas fir pole would provide this moment capacity at the groundline.

11.4.2 Additional Examples Showing the Application of Loads and the Use of Strength and Load Factors: Chapters 13 and 14 demonstrate the application of strength and load factors in the structural analyses examples.

TABLE 11-6
RECOMMENDED LOAD FACTORS AND STRENGTH FACTORS
TO BE APPLIED TO NESC DISTRICT LOADS
(Grade B New Construction)
(NESC Tables 253-1 and 261-1A) (Note 5)

FACTORS	NESC	RUS
LOAD FACTORS		
Vertical Loads	1.50	1.50
Transverse Loads		
Wind	2.50	2.50
Wire Tension	1.65	1.65
Longitudinal Loads		
At crossings		
General	1.10	1.33
Deadends	1.65	1.65
Elsewhere		
General	1.00	1.33
Deadends	1.65	1.65
STRENGTH FACTORS (Note 3)		
Steel and Prestressed Concrete Structures	1.00	1.00
Wood Poles (Note 4)	0.65	0.65
Wood Crossarms (Note 4)	0.65	0.50
Guy Wire Assemblies	0.90	0.65 (Note 1)
Guy Anchors and Foundations	1.00	0.65
Guy Attachment Assemblies (includes guy hardware)	1.00	0.65 (Note 2)
Conductor Support Hardware (Note 6)	1.00	1.00

Notes:
1. A value different than 0.65 may be used, but should not exceed 0.9.
2. This strength factor of 0.65 may be increased for steel and prestressed concrete poles.
3. It is recognized that structures will experience some level of deterioration after installation. These strength factors are for new construction.
4. For wood structures, when the deterioration reduces the structure strength to 2/3 of that required when installed, the wood structure should be replaced or rehabilitated. If the structure or structure component is replaced, the structure or structure component needs to meet the strength for the original grade of construction. The rehabilitated portions of the structures have to be greater that 2/3 of that required when installed for the life of the line.
5. When calculating the additional moment due to deflection, deflections should be calculated using loads prior to application of the load factor.
6. Conductor Support Hardware is any hardware not a part of the structure, guy assembly, or guy attachment. Conductor support hardware may be splices, extension links, insulator string yokes, y-clevis balls, ball hooks, deadend clamps, etc.

TABLE 11-7
RECOMMENDED LOAD FACTORS AND STRENGTH FACTORS
TO BE APPLIED TO EXTREME WIND LOADS (Rule 250C of the NESC)
AND TO EXTREME WIND/ICE LOADS (Rule 250D of the NESC)
(Grade B New Construction)
(NESC Tables 253-1 and 261-1A) (Note 5)

FACTORS	NESC	RUS
LOAD FACTORS		
Vertical Loads	1.00	1.10
Transverse Loads		
Wind	1.00	1.10
Wire Tension	1.00	1.00
Longitudinal Loads		
At crossings		
General	1.00	1.00
Deadends	1.00	1.10
Elsewhere		
General	1.00	1.00
Deadends	1.00	1.10
STRENGTH FACTORS (Note 3)		
Steel and Prestressed Concrete Structures	1.00	1.00
Wood Poles (Note 4)	0.75	0.75
Wood Crossarms (Note 4)	0.75	0.65
Guy Wire Assemblies	0.90	0.65 (Note 1)
Guy Anchors and Foundations	1.00	0.65
Guy Attachment Assemblies (includes guy hardware, bracket and guy attachment assemblies)	Not Specified	0.65 (Note 2)
Conductor Support Hardware (Note 6)	0.80	0.80

Notes:
1. A value different than 0.65 may be used, but should not exceed 0.90.
2. This strength factor of 0.65 may be increased for steel and prestressed concrete poles.
3. It is recognized that structures will experience some level of deterioration after installation. These strength factors are for new construction.
4. For wood structures, when the deterioration reduces the structure strength to 2/3 of that required when installed, the wood structure should be replaced or rehabilitated. If the structure or structure component is replaced, the structure or structure component needs to meet the strength for the original grade of construction. The rehabilitated portions of the structures have to be greater that 2/3 of that required when installed for the life of the line.
5. When calculating the additional moment due to deflection, deflections should be calculated using loads prior to application of the load factor.
6. Conductor Support Hardware is any hardware not a part of the structure, guy assembly, or guy attachment. Conductor support hardware may be splices, extension links, insulator string yokes, y-clevis balls, ball hooks, deadend clamps, etc.

12. FOUNDATION STABILITY OF DIRECT-EMBEDDED POLES

12.1 General: Every structure standing above ground is subjected to lateral forces. In the case of direct-embedded wood, steel or prestressed concrete transmission structures, it is desirable to depend on the earth to resist lateral forces. The embedded portion of a pole provides this resistance by distributing the lateral load over a sufficient area of soil. A properly selected embedment depth should prevent poles from kicking out. With time, single poles may not remain plumb. Leaning of single pole structures is sometimes permitted, provided excessive angular displacements are avoided, pole strength is adequate considering additional loads from the pole being out of plum and adequate clearances are maintained.

The lateral forces to which wood transmission structures are subjected are primarily forces due to wind and wire tension loads due to line angles. Longitudinal loads due to deadending or uniform ice on unequal spans should be examined to see how they affect embedment depths. Normally, flexible transmission structures are stabilized longitudinally by the overhead ground wire and phase conductors.

Bearing and lateral earth capacity of soils depend on soil types and soil characteristics such as internal friction, cohesion, unit weight, moisture content, gradation of fines, consolidation and plasticity. Most soils are a combination of a cohesive soil (clay) and cohesionless soil (sand).

12.2 Site Survey

12.2.1 Soil Borings: Depending on the transmission line and knowledge of the soil conditions along the corridor, soil borings may or may not be taken. If the line is composed of H2 or higher class wood poles, or equivalent strength steel or concrete poles, the engineer may elect to take soil borings. The decision to take borings will also depend on existing soil information. Variation of the soil will determine the frequency of the borings. Borings might also be considered at unguyed angle structures and deadend structures composed of steel or concrete poles.

12.2.2 Embedment Depths: In deciding embedment depths for many typical agency borrower wood pole construction, economics dictate that few, if any, soil borings be taken when data and experience from previous lines are available. Numerous soil conditions will be encountered in the field. Although the soil conditions may closely resemble each other, the soils may have a wide range of strengths. The engineer, therefore, has to identify areas or conditions where pole embedment depths in soil may have to be greater than the minimum depth of 10 percent, plus 2 feet.

Areas where the designer needs to consider additional embedment depths include (but are not limited to):

- Low areas near streams, rivers, or other bodies of water where a high water table or a fluctuating water table is probable. Poles in a sandy soil with a high water table may "kick" out. Due to the lubricating action of water, frictional forces along the surface area of embedded poles are reduced. The legs of H-frames may "walk" out of the ground if neither sufficient depth nor bog shoes are provided to resist uplift. Guy anchors may fail if the design capacity does not consider the submerged weight of the soil.

- Areas where the soil is loose such as soft clay, poorly compacted sand, pliable soil, or soil which is highly organic in nature.

- Locations where higher safety is desired. This may be at locations of unguyed small angle structures where a portion of the load is relatively permanent in nature, or at river, line, or road crossings.

- Locations where poles are set adjacent to or on steep grades.

- Locations where more heavily loaded poles are used.

- Locations where underground utilities such as water or sewer will be located next to the pole.

12.2.3 Field Survey: A field survey is necessary in order to judge whether a soil is "good," "average," or "poor." There are several economical methods to make a field survey for wood transmission lines. The engineer may use a hand auger, light penetrometer, or torque probe. The meaning of terms such as firm, stiff, soft, dense, and loose may not always be clear. Table 12-1 will help to clarify these terms:

TABLE 12-1
CLASSIFICATION OF SOILS BASED ON FIELD TESTS

Term	Field Test
Very soft	Squeezes between fingers when fist is closed
Soft	Easily molded by fingers
Firm	Molded by strong pressure of fingers
Stiff	Dented by strong pressure of fingers
Very Stiff	Dented only slightly by finger pressure
Hard	Dented only slightly by pencil point
Term	Field Test
Loose	Easily penetrated with a 1/2 in. reinforcing rod pushed by hand
Firm	Easily penetrated with a 1/2 in. reinforcing rod driven with a 5 lb. hammer
Dense	Penetrated 1 ft. with a 1/2 in. reinforcing rod with a 5 lb. Hammer
Very dense	Penetrated only a few inches with a 1/2 in. reinforcing rod driven with a 5 lb. hammer

12.3 Pole Stability

12.3.1 Wood Poles: In addition to local experience with wood poles, the graphs in Figures 12-1 through 12-3 may be used to approximate embedment depths. To use the charts, good, average, and poor soils have to be defined. The following are proposed as descriptions of good, average, and poor soils:

Good: Very dense, well graded sand and gravel, hard clay, dense, well graded, fine and coarse sand.

Average: Firm clay, firm sand and gravel, compact sandy loam.

Poor: Soft clay, poorly compacted sands (loose, coarse, or fine sand), wet clays and soft clayey silt

The graphs in Figures 12-1 through 12-3 are based on Equation 12-1:

$$P = \frac{S_e D_e^{3.75}}{L - 2. - .662 D_e} \qquad \text{Eq. 12-1}$$

where:

P = horizontal force in pounds 2 feet from the top that will overturn the pole
S_e = Soil constant
140 for good soils
70 for average soils
35 for poor soils
D_e = embedment depth of pole in feet.
L = total length of pole in feet.

Embedment depth can be determined once an equivalent horizontal load 2 feet from the top is calculated. This horizontal load is calculated by dividing the total ground line moment by the lever arm to 2 feet from the top of the pole.

Equation 12-1 is taken from "Effect of Depth of Embedment on Pole Stability," Wood Preserving News, Vol X, No. 11, November, 1932.

Some general observations can be made concerning wood pole embedment depths:

- The rule of thumb of "10 percent + 2 ft." is adequate for most wood pole structures in good soil and not subjected to heavy loadings.
- For Class 2 and larger class poles and poles of heights less than 60 ft., pole embedment depths should be increased 2 ft. or more in poor soil (single pole structures).
- For Class 2 and larger class poles and poles of heights less than 40 ft., pole embedment depths should be increased 1-2 ft. in average soil (single pole structures).
- For H-frame wood structures, "10 percent + 2 ft." seems to be adequate for lateral strengths. Embedment depths are often controlled by pullout resistance.

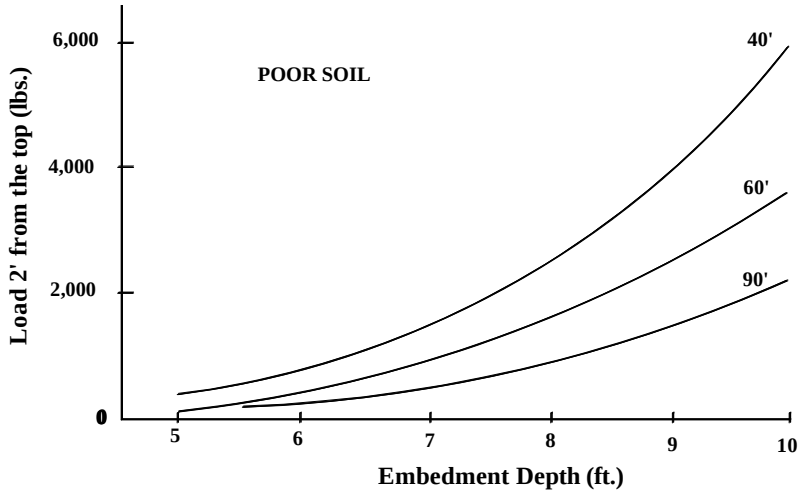


FIGURE 12-1: EMBEDMENT DEPTHS IN POOR SOIL

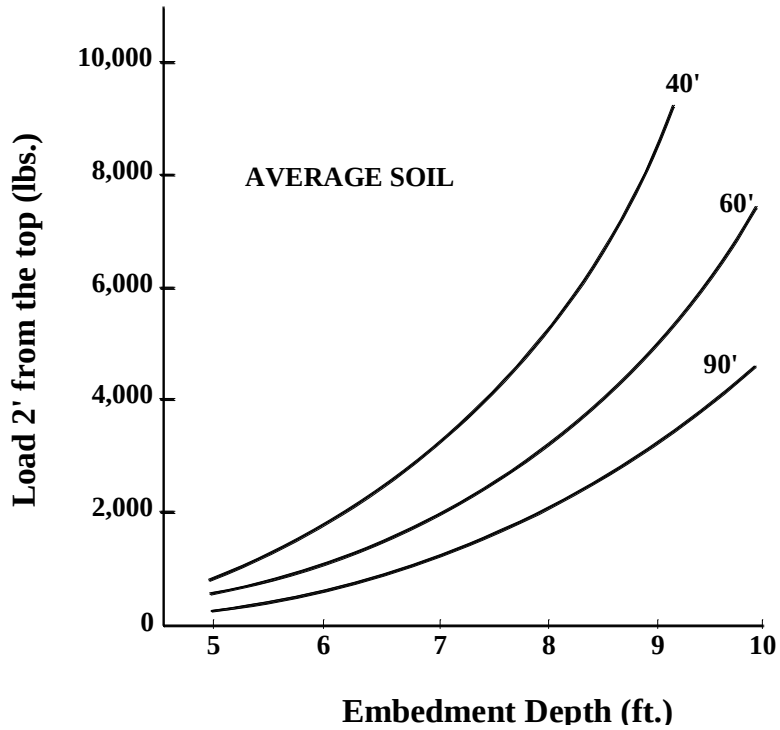


FIGURE 12-2: EMBEDMENT DEPTHS IN AVERAGE SOIL

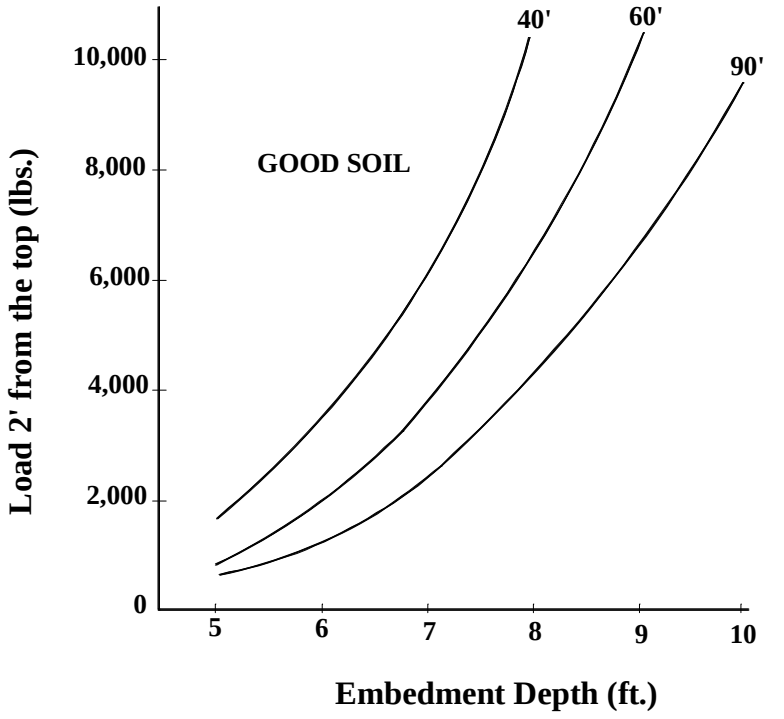


FIGURE 12-3: EMBEDMENT DEPTHS IN GOOD SOIL

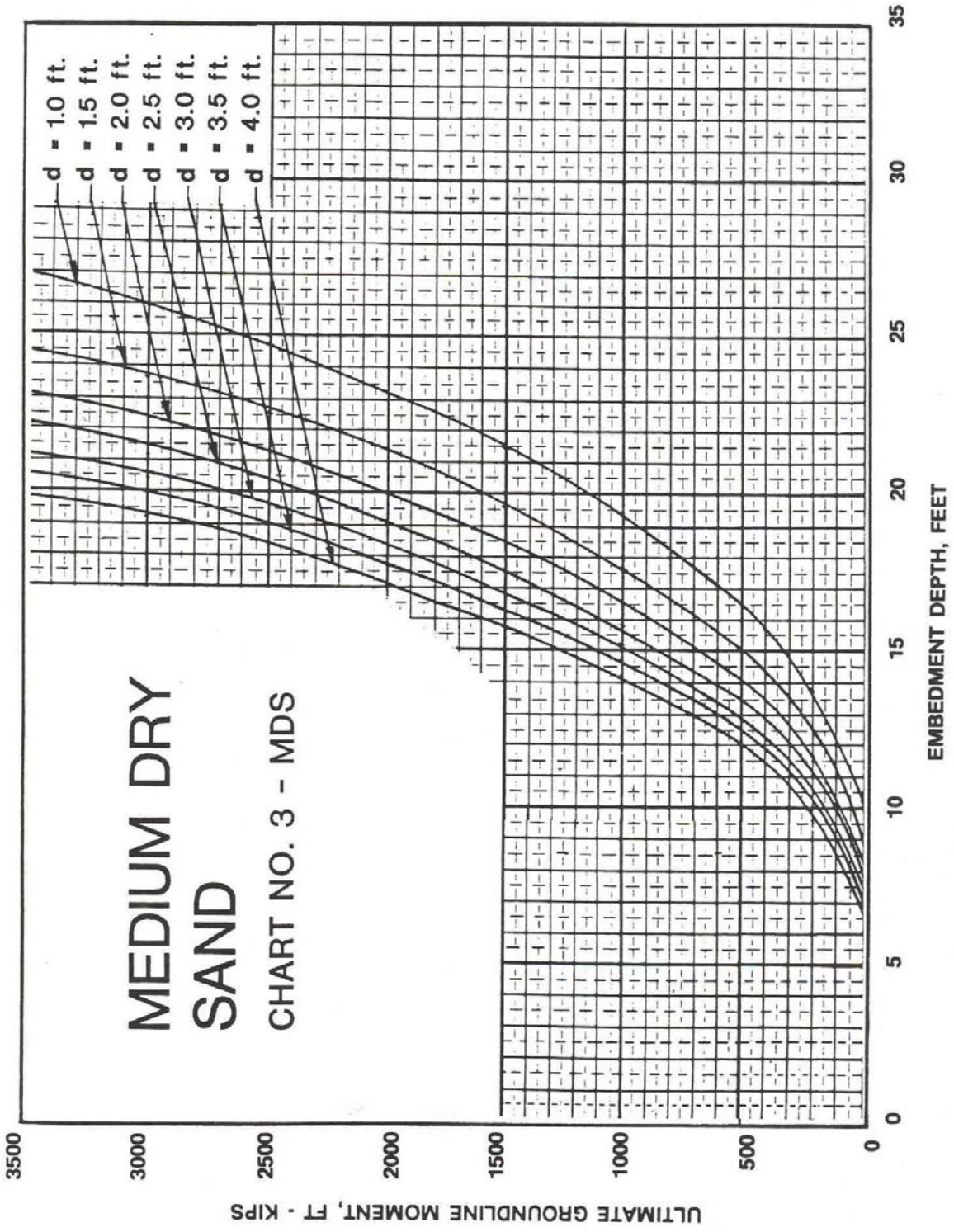


FIGURE 12-4: EMBEDMENT CHART FOR MEDIUM DRY SAND
AGENCY BULLETIN 1724E-205 “EMBEDMENT DEPTHS FOR CONCRETE AND STEEL POLES”

12.3.2 Direct Embedded Steel and Concrete Poles: In agency Bulletin 1724E-205, "Embedment Depths for Concrete and Steel Poles," embedment charts are provided for concrete and steel transmission poles sustaining relatively large overturning moments. The information in Bulletin 1724E-205 may be used to approximate embedment depths for cost estimates, to make preliminary selection of embedment depths and to verify or check selection of embedment depths based on other or more exact methods. Sample calculations illustrating the use of the embedment charts and illustrating the use of design methods for those occasions when the charts cannot be used, are also provided in Bulletin 1724E-205.

In that bulletin, nine embedment charts have been developed for nine soil types. These charts show embedment depths for pole diameters ranging from 1.0 to 4.0 feet and ultimate moments at groundline up to 3500 ft-kips. A sample chart for medium sand is shown in Figure 12-4 of this bulletin.

Several computer programs exist for determining embedment depths for steel and concrete poles. Such programs may provide a more efficient selection of embedment depths in preliminary design and their use should be considered in any final design.

12.3.3 Replumbing: If a search of previous experience in an area indicates that single pole lines have had to be replumbed, there are several methods which should be considered in order to reduce the frequency of replumbing of a new line to be located in the same area. These methods are as follows:

- Use a lower grade species of wood in order to increase embedment diameters. For instance, embedment diameters for Class 1 Western red cedar poles will be greater than embedment diameters for Douglas fir.
- Use aggregate backfill.
- Install a pole key with or without a pole toe of crushed stone, gravel, or concrete.
- Embed one foot deeper (or more).
- In the case of more heavily loaded steel and prestressed concrete poles, consideration should be given to the use of concrete backfill.

12.4 Bearing Capacity: To prevent a guyed pole from continually sinking into the ground due to induced vertical loads, the pole butt should provide sufficient bearing surface area. If little soil information is available, local building codes (Table 12-2) might be helpful in determining allowable bearing capacities. These values are usually conservative and reflect the hazards associated with differential deflection in a building. Fortunately, transmission lines can sustain deflections on the order of several times that of buildings without detrimentally affecting their performance. The bearing capacity of guyed poles is not as critical as that for buildings. Good engineering judgment and local experience should be used in determining if bearing capacities of a certain soil will be exceeded by guyed poles. Table 12-3 suggests ranges of ultimate bearing capacities.

TABLE 12-2
PRESUMPTIVE ALLOWABLE BEARING CAPACITIES, ksf

Soil Description	**Chicago 1966**	**Atlanta 1950**	**Uniform Building Code 1964**
Clay, very soft	0.5	2.0	1.5
Clay, soft	1.5	2.0	1.5
Clay, ordinary	2.5	4.0	
Clay, medium stiff	3.5		2.5
Clay, stiff	4.5	4.0	
Clay, hard	6.0		8.0
Sand, compact and clean	5.0		
Sand, compact and silty	3.0		
Inorganic silt, compact	2.5		1.5
Sand, loose and fine			1.5
Sand, loose and coarse, or sand-gravel mixture, or compact and fine			2.5
Gravel, loose, and compact coarse sand		8.0	8.0
Sand-gravel, compact		12.0	8.0
Hardpan, cemented sand, cemented gravel	12.0	20.0	
Soft rock			
Sedimentary layered rock (hard shale, sandstone, siltstone)		30.0	
Bedrock	200.0	200.0	

TABLE 12-3
SUGGESTED RANGES OF PRESUMPTIVE
ULTIMATE BEARING CAPACITIES, psf*

Specific Description (Dry)	**psf**
Clay, soft	2000 - 6000
Clay, ordinary	6000 - 9000
Clay, stiff	12000
Clay, hard	15000
Sand, loose	4500
Sand, compact and silty	9000
Sand, compact and clean	15000
Hardpan	40000
General Description (Dry)	
Poor Soil	1500 - 4000
Average Soil	5000 – 9000
Good soil	12000 - 18000

Note:
Ultimate values are based on three times allowable. The values in the table are considered approximate. For more accurate bearing capacity values, bearing capacity equations should be used.

12.5 Uplift: When H-frame structures with X-braces are subject to overturning forces, one leg will be in compression and one leg in tension. The skin friction assumed in design should be based on past experience encountered by the engineer, experience of nearby lines, and the results of the field survey. The following may be appropriate for average soil:

- If the soil is wet or subject to frequent wettings, an ultimate skin friction not greater than 100 psf should probably be assumed;
- If native soil is used as backfill, an ultimate skin friction between 100 and 500 psf should be assumed, provided the soil is not subject to frequent wettings;
- If an aggregate backfill is used, an ultimate skin friction between 250 and 1000 psf may be possible;
- Pole "bearing" shoes increase uplift capacity of a dry hole with natural backfill on the order of 2 to 2.5 times. The use of aggregate backfill with bearing shoes is usually not necessary provided the native backfill material is of relatively good material; and
- In many cases, double cross-braced H-frame structures may require uplift shoes.

12.6 Construction - Backfill: Lateral and uplift resistance of wood poles will depend not only on type of soil, moisture content of the soil, depth of setting, but also on how well the backfill has been tamped.

All water should be removed before backfilling. If native backfill material is to be used, it should be free of grass, weeds, and other organic materials. If the dirt removed from the hole is too wet or has frozen, dry, unfrozen material should be obtained for the backfill. Where the earth removed from the hole is unsuitable as backfill, special backfill should be specified by the engineer. Drawing TM-101 included in agency Bulletins 1728F-810 and 811 suggests a gradation of aggregate to be used as backfill material.

When backfilling, the soil should be placed and compacted in shallow layers (approximately 6 inch layers). Each layer should be compacted until the tamp makes a solid sound as the earth is struck. Power tamping is preferred using two power tampers and one shoveler. The importance of proper compaction of the backfill cannot be overemphasized. Insufficient tamping is a common source of trouble and has been the cause of some failures.

13. STRUCTURES

13.1 Economic Study: During preliminary planning stages of lines above 161 kV, studies should be made to evaluate the economics of different types of structures as related to conductor size. In most instances, for lines of 230 kV and below, wood structures have historically been the economical choice. However, in more heavily loaded situations (larger wires, longer spans) steel and prestressed concrete structures may be more economical than wood, especially considering the long-term maintenance costs associated with wood structures. In some instances, other types of material have been used because of environmental or meteorological constraints. For voltages 345 kV and above, it may be difficult to obtain long span construction utilizing wood, due to height or strength reasons.

In most instances, for lines 230 kV and below, an economic study can help to determine structure configuration, base pole class (wood, steel or prestressed concrete) and height.

Factors which limit structure spans include:

a. Strength: Horizontal spans are limited by crossbrace, poles, etc. Vertical spans are limited by crossarms, structure strength. For H-frame structures, horizontal and vertical spans are also limited by pullout resistance for H-frame structures.

b. Conductor Separation: Conductor separation is intended to provide adequate space for line crew personnel on poles, prevention of contact and flashover between conductors.

c. Clearances-to-Ground: Limits on spans are directly related to height of structures.

d. Insulator Swing: The ratio of horizontal to vertical span will be limited by insulator swing and clearance to structure.

Historically, preliminary cost estimates have been usually based on level ground spans. With the advent of computer-automated line design and optimization software, preliminary cost estimates can now be performed using a preliminary profile digitized from the United States Geological Survey (USGS) topographic maps or from other sources. An economic study should consider material costs, cost of foundations and erection, different structure heights, hardware costs, and right-of-way costs. The estimates are intended to give borrowers an idea as to relative rankings of various structure types and configurations such as steel lattice, steel pole, prestressed concrete pole, and wood H-frame or single pole. However, in the decision-making process, the manager may want to consider as part of the evaluation such intangibles as importance of the line to the power system, appearance, material availability, and susceptibility to environmental attack. In some areas, State or local constraints may ignore economics and specify the type of structure to be used.

The level ground span used to develop preliminary cost estimates in the economic study is determined from clearance-to-ground and structure strength. Developing a graph, as shown in Figure 13-1, is one means of determining the level ground span (points A and B). Structure cost per mile can be related to pole height and class of poles as shown in Figure 13-2. To keep the cost down, the line design should be based on one tangent structure type and one or two pole classes for the majority of the line. For H-frame structures, the engineer should consider double crossbraced structures, as well as single crossbraced structures.

With the help of computer automated line design and optimization software, an economic study can be accomplished almost concurrently with the line design. If a land profile is available, or developed from USGS maps, the line designer may want to use optimization software to help

determine the most economic line design. With such software, different structure types and materials and different conductor types can be evaluated. An advantage of optimization software is the use of the actual terrain (rather than level ground span) or a good approximation of the terrain. Optimization algorithms can fit structure height and type to the terrain, and can make use of different structure heights and configurations. The major disadvantage of optimization software is that it requires input and analysis of large amounts of data.

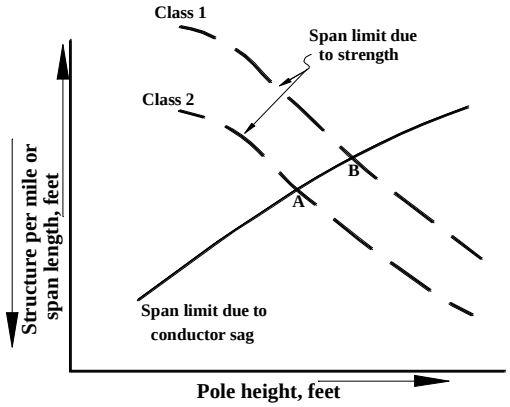


FIGURE 13-1: SELECTION OF LEVEL GROUND SPAN

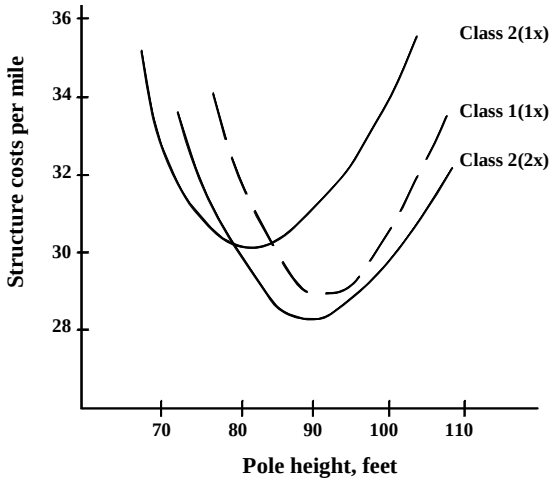


FIGURE 13-2: STRUCTURE COST PER MILE RELATED TO POLE HEIGHT

13.2 <u>Steel and Concrete Structures - General Design Considerations</u>: Rural Utilities Service provides several bulletins on design considerations for steel and concrete pole structures.

- 1724E-204, "Guide Specifications for Steel Single Pole and H-Frame Structures,"
- 1724E-214, "Guide Specification for Standard Class Steel Transmission Poles,"
- 1724E-206, "Guide Specification for Spun, Prestressed Concrete Poles and Concrete Pole Structures,"
- 1724E-216, "Guide Specification for Standard Class Spun, Prestressed Concrete Transmission Poles."

The bulletins include sample purchase specifications, design considerations, and suggested drawings and example design calculations.

13.3 Wood Structures - General Design Considerations

13.3.1 Stress Limitations: The structural stress limitations set forth in Table 13-1 are recommended for transmission lines using agency standard wood pole construction. These values assume that the wood has not deteriorated due to decay occurring in the manufacturing process.

TABLE 13-1
DESIGNATED STRESSES FOR POLES

Kind of Wood	Modulus of Elasticity x 1000 (psi)	Designated Ultimate Bending Stress (M.O.R.)* (psi)
Western larch	1710	8400
Southern yellow pine	1800	8000
Douglas fir	1920	8000
Lodgepole pine	1340	6600
Jack pine	1220	6600
Red (Norway) pine	1800	6600
Ponderosa pine	1260	6000
Western red cedar	1120	6000
Northern white cedar	800	4000

*M.O.R. = Modulus of Rupture

Douglas fir and Southern yellow pine (SYP) are used for crossarms. Southern yellow pine has four species which are long leaf (most popular species), loblolly, shortleaf, and slash. The coast type Douglas fir is the only type which should be used when specifying Douglas fir for crossarms. Table 13-2 gives strength properties to be used in crossarm design.

TABLE 13-2
DESIGNATED STRESSES FOR CROSSARMS

Kind of Wood	Modulus of Elasticity x 1000 (psi)	Designated Ult. Bending Stress (M.O.R.)* (psi)	End Grain Max Crushing Strength (psi)	Across Grain Stress (psi)	Shear Parallel to Grain (psi)
Douglas fir	1920	7400	7420	910	1140
SYP	1800	7400	7070	1000	1310

*M.O.R. = Modulus of Rupture

13.3.2 Preservative Treatment: The decay of poles results from fungi and other low forms of plant life which attack untreated poles or poles with insufficient preservative. Damage by insect attack (termites, ants, and wood borers) is also associated with decay. When preservative retention is low, wood cannot resist attacks by fungi and insects. There are two general classes of preservative treatment.

Oil-Borne Using Creosote, Penta and Copper Naphthenate in Petroleum**:** Creosote oil was the predominant preservative for poles on rural systems until about 1947. Post-war shortages prompted the introduction of pentachlorophenol (penta) and copper naphthenate dissolved in the fuel oils, and other preservatives.

Waterborne Using Arsenates of Copper**:** Poles using waterborne arsenates of copper (CCA, ACA and ACZA) are green in appearance. These preservatives were developed before World War II and have proven very effective as wood preservatives around the world. For

species and amounts of treatment, refer to agency Bulletin 1728F-700, "Specification for Wood Poles, Stubs, and Anchor Logs."

13.3.3 Structure Designations for Single Wood Pole Structures: Single pole wood structures are mainly limited in use to 115 kV and below. The six primary standard single pole structures utilized by Rural Utilities Service borrowers are designated as:

- TP - pin or post insulators
- TPD - pin or post insulators, double circuit
- TS - suspension insulators, crossarm construction
- TSD - suspension insulators, crossarms, double circuit
- TSZ - suspension insulators, "wishbone" arm construction
- TU - suspension insulators, steel upswept arm construction

13.4 Design Calculations for Single Wood Pole Structures

13.4.1 Maximum Horizontal Span Limits of Single Wood Pole Structures: The following conditions should be taken into account when determining horizontal spans as limited by pole strength for tangent structures:

- Wind on the conductors and OHGW is the primary load. 75 to 90 percent of the horizontal span will be determined by this load.

- Wind on the structure will affect the horizontal span by 5 to 15 percent.

- Unbalanced vertical load will increase ground-line moments. For single circuit structures, one phase is usually left unbalanced. The vertical load from the conductor will induce moments at the groundline and will affect horizontal span lengths by 2 to 10 percent.

- P-delta (P-δ) moments will also increase induced ground line moments. As a transverse load is applied to a structure, the structure will deflect. This deflection will offset the vertical load an additional amount " δ " causing an additional moment of the vertical weight times this deflection. This additional moment due to deflection is a secondary effect. An approximate method for taking into account the p-δ moments is given in section 13.4.2.

For wood structures, depending on the taper of the pole, the maximum stress may theoretically occur above the ground level. The general rule of thumb is that if the diameter at ground level is greater than one and a half times the diameter where the net pull is applied, the maximum stress occurs above the ground level. Even if the point of maximum stress occurs above the groundline for single base wood pole structures, one can assume that spans are based on groundline moments in accordance with Exception 1 in NESC Rule 261A.2. Exception 1 states: "When installed, naturally grown wood poles acting as single-based structures or unbraced multiple-pole structures, shall meet the requirements of Rule 261A.2a without exceeding the permitted stress level at the ground line for unguyed poles or at the points of attachment for guyed poles."

The strength of the crossarm has to be checked to determine its ability to withstand all expected vertical and longitudinal loads. When determining bending stress in crossarms, moments are calculated at the through bolt, without considering the strength of the brace. The vertical force is determined by the vertical span under those conditions which yield the maximum vertical weight. The strength of two crossarms will be twice the strength of one crossarm. When considering the strength of the crossarm to withstand longitudinal loadings, reduction in the moment capacity due to bolt holes should be taken into account.

Equation 13-1 is the general equation for determining the moment induced in the pole from the applied loads represented in Figure 13-3. This equation may be used to determine the maximum horizontal span as demonstrated in the example in Paragraph 13.4.2.

$$\phi M_A = M_g = (LF)M_{wp} + (LF)M_{wc} + (LF)M_{vo} + (LF)M_{p-\delta} \qquad \text{Eq. 13-1}$$

where:

ϕ = strength factor, see Chapter 11

M_A = F_bS, the ultimate groundline moment capacity of the pole, ft-lbs. For moment capacities of wood poles at the groundline, (see Appendix F);
F_b = designated ultimate bending stress (M.O.R.)
S = section modulus of the pole at the groundline (see Appendix H).

LF = load factor associated with the particular load

M_g = induced moment at the ground line

Other symbols are defined by Equations 13-2, 13-3, 13-4, 13-5.

When estimating the load carrying capacity of a pole using manual methods, it is difficult to assess the additional moment due to deflection. Equations 13-5 and 13-6 provide an approximate way to calculate the additional moment due to defection. Because $M_{p-\delta}$ is a function of the vertical span (VS), the engineer should make an assumption about the relationship between the vertical and horizontal span (HS). In Equations 13-4 and 13-5, the relationship used is: VS = 1.25HS.

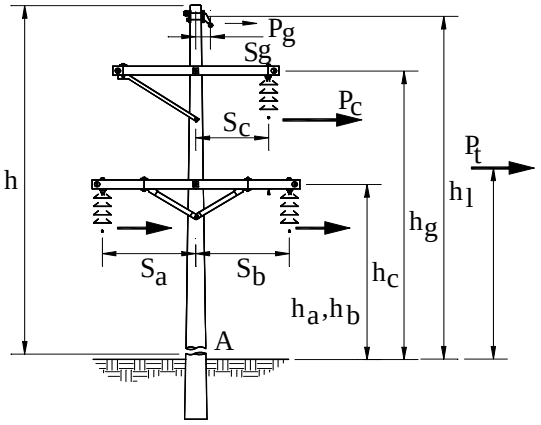


FIGURE 13-3: TS TYPE STRUCTURE

Refer to Figure 13-3 when considering the equations and symbols that follow.

a. M_{wp} = groundline moment due to wind on the pole

$$M_{wp} = \frac{(F)(2d_t + d_a)(h)^2}{72} \qquad \text{Eq. 13-2}$$

where:

F = wind pressure, psf

d_t = diameter of pole at top, inches

d_a = diameter of pole at groundline, inches

h = height of pole above groundline, feet

b. M_{wc} = groundline moment due to wind on the wires

$$M_{wc} = p_t(h_1)HS \qquad \text{Eq. 13-3}$$

where:

HS = horizontal span, feet

h_1 = moment arm of p_t, feet; in the example,

$$h_1 = \frac{(h_a)(p_c)+(h_b)(p_c)+(h_c)(p_c)+(h_g)(p_g)}{P_t} \qquad \text{Eq. 13-3a}$$

p_t = sum of transverse unit wire loads, lbs/ft; in example, $p_t = 3\ p_c + p_g$ single circuit, single pole structures

c. M_{vo} = groundline moment due to unbalanced vertical load

$$M_{vo} = 1.25HS(w_c s_t + w_g s_g) + W_i s_t \qquad \text{Eq. 13-4}$$

where:

s_g = Horizontal distance from center of pole to ground wire (positive value on one side of the pole, negative on the other), feet

s_t = $s_a + s_b + s_c$, where s_a , s_b ,and s_c are horizontal distances from center of pole to conductors (positive value on one side of the pole, negative on the other), feet

w_c = weight of the conductor per unit length, lbs./ft.

w_g = weight of overhead groundwire per unit length, lbs./ft.

W_i = weight of insulators, lbs.

d. $M_{p\text{-}\delta}$ = groundline moment due to pole deflection

$$M_{p\text{-}\delta} = 1.25HS(w_t)\delta_{imp} \qquad \text{Eq. 13-5}$$

where:

w_t = total weight per unit length of all wires, lbs./ft.

δ_{imp} = improved estimate of deflection of the structure, ft.

$$\delta_{imp} = \left(\frac{\left(6.78(p_t)(HS)(h_c)^3 144\right)}{E(d_a)^3(d_1)}\right)\delta_{mag} \qquad \text{Eq. 13-6}$$

E = modulus of elasticity, psi

d_a = diameter of pole at location "A" (groundline), inches

d_1 = diameter of pole at height "h_1" inches

δ_{mag} = deflection magnifier, no units, (assume 1.15 initially)

h_c = effective height to the conductors, feet

HS = horizontal span, feet

p_t = total transverse load per unit length of all wires, lbs./ft.

After substitutions of M_{wp}, M_{wc}, M_{vo}, and $M_{p\delta}$ have been made into Eq.13-1, the equation can be reduced to a quadratic equation (below) and solved for the horizontal span. (See Paragraph 13.4.2 for an example of how the calculation of HS is carried out.)

$$a(HS)^2 + b(HS) + c = 0$$

$$HS = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \qquad \text{Eq. 13-7}$$

Once "HS" has been calculated, check the assumption of $\delta_{mag} = 1.15$:

$$\delta_{mag} = \frac{1}{1 - \frac{1.25HS(W_t)}{P_{cr}}} \qquad \text{Eq. 13-8}$$

(See Chapter 14 for calculations of P_{cr})

13.4.2 Example of Maximum Horizontal Spans: Determine the maximum horizontal span for the 69 kV TSS-1 wood structure (Figure 13-4). Terrain is predominantly level, flat, and open. ("s_g" is negligible; see Equation 13-4). Location and magnitude of resultant loads are indicated in Figure 13-5.

Given**:**

NESC Heavy Loading	
Extreme wind	19 psf on the wires 22 psf on the structure
Extreme Ice with Concurrent Wind(EI&W)	4 psf, 1 inch radial ice
Pole:	Western red cedar
Conductor:	266.8 kcmil, 26/7 ACSR (Partridge)
Ground wire:	3/8" H.S.S.

Conductor loads, lbs./ft**:**

	Heavy	High Wind	EI&W
Transverse	0.5473	1.0165	.8808
Vertical	1.0776	0.3673	2.402

Ground wire loads, lbs./ft**:**

	Heavy	High Wind	EI&W
Transverse	0.4533	0.5700	.7868
Vertical	0.8079	0.2730	1.9667

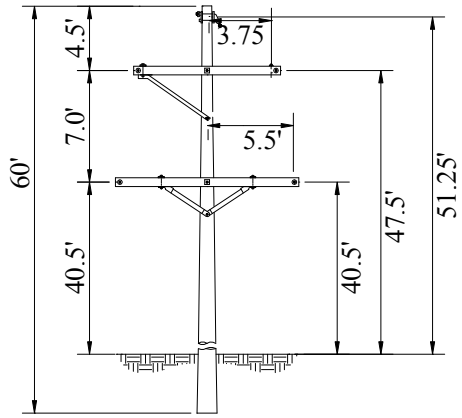


FIGURE 13-4: TSS-1 STRUCTURE

Other information**:**

F_b(pole)	=	6000 psi
F_b (crossarm)	=	7400 psi
S(groundline)	=	458 in^3
S(crossarm)	=	22.7 in^3
Wt. of insulator	=	58 lbs.
Dia. (top)	=	8.59 in.
Dia. (groundline)	=	16.72 in.
p_t(total unit load)	=	3(0.5473)+.4533 = 2.10 lbs./ft.
w_t(total unit load)	=	3(1.0776)+0.8079 = 4.41 lbs./ft
P_{cr}(critical buckling load)	=	17,900 lbs. (see chapter 14 for fix–free condition) , ℓ =44.6 ft., E=1.12 E 06 psi d_a = 9.63 in., d_g = 16.72 in., I_a=422 in^4

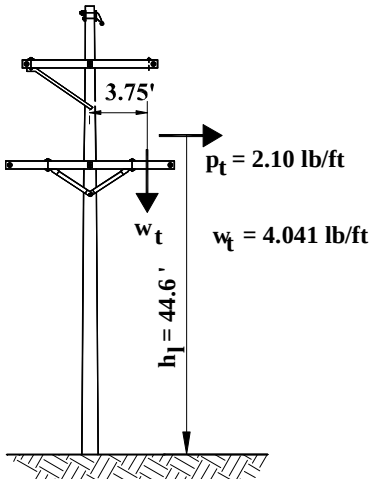


FIGURE 13-5: APPLICATION OF FORCES (HEAVY LOADING)

Solution for Maximum Horizontal Span Considering P-δ moments**:** A comparison of unit loads with load factors indicates that the Heavy Loading District Loads control design. Therefore, for Heavy Loading, the moments for Equation 13-1 are calculated.

a. $M_{wp} = \dfrac{4[(2)(8.59+16.72)](52)^2}{6(12)}$

$= 5{,}100\, ft - lbs.$

b. $M_{wc} = (2)(0.5473)(40.5)HS + (0.5473)(47.5)HS + (0.4533)(51.25)HS$

$= 93.5HS$

c. $M_{vo} = [(3.75)(1.0776) - .8075(.5)]HS(1.25) + W_i s_t$

$= 4.45HS + 217$

d $M_{p\delta} = (1.25)(HS)(4.041)\delta_{imp}$

$$\delta_{imp} = \frac{6.78(2.095)(HS)(44.6)^3(144)}{(1.12E06)(16.72)^3(9.63)}\delta_{mag}$$

$$\delta_{imp} = .003558(1.15)HS$$

$$\delta_{imp} = .0041HS$$

$$M_{p\delta} = (1.25)(4.041)(HS)(.0041)(HS)$$

$$= .0207(HS)^2$$

e. $\phi M_a = (LF)M_{wp} + (LF)M_{wc} + (LF)M_{vo} + (LF)M_{p\delta}$

$(.65)(229{,}000) = (2.5)(5{,}100) + (2.5)(93.5)HS + 1.5(4.45)HS + 1.5(217) + 1.5(.0207)HS^2$

$148{,}524 = (2.5)(5{,}100) + (1.5)(187) + (2.5)(93.5)HS + 1.5(5.56)HS + 1.5(.0207)HS^2$

$.0311HS^2 + 241.32HS - 135{,}820 = 0$

f. $a(HS)^2 + b(HS) + c = 0$

$.0311(HS)^2 + 241.32(HS) - 135{,}775 = 0$

$$HS = \frac{-241.32 + \sqrt{241.32^2 - 4(.0311)(-135{,}775)}}{2(.0311)}$$

$HS = 527$ feet

g. Once the HS has been calculated, the assumption of 1.15 as the magnifier should be checked. Pcr = 17,900 assuming fixed free conditions (See Chapter 14).

$$\delta\text{mag} = \frac{1}{1 - \dfrac{(W_t)1.25HS}{P_{cr}}} = 1.15$$

$$\delta\text{mag} = \frac{1}{1 - \dfrac{(4.0407)(1.25)(525)}{17{,}900}}$$

.

$= 1.175$ Recalculate assuming 1.17 as the deflection magnifier, HS = 529 feet.

h. Lateral Stability: The Equivalent load 2 feet from the top is approximately 4400 lbs. From Figure 12-2 (average soil), the embedment depth for a 4400 lb. load 2 feet from the top is between 8 and 8.5 feet. Lines nearby have performed well with the standard embedment depths. Engineering judgment dictates that an 8 foot embedment depth for the 60 foot pole will be sufficient.

13.4.3 Maximum Vertical Span for TP and TS Pole Top Assemblies: To determine the vertical span, the moment capacity of the arm at the pole is calculated.

Calculations for these structures are:

$$VS = \frac{\phi M_{x-arm} - (LF)(W_i)(s_c)}{(LF)(w_c)(s_c)} \qquad \text{Eq. 13-9}$$

where:

$M_{x\text{-}arm}$ = $F_b S$, moment capacity of the arm, ft-lbs.
F_b = the designated bending stress.
S = the section modulus of the arm (see Appendix G.)
w_c = weight of the conductor per unit length, lbs./ft.
s_c = moment arm, meters (feet).
W_i = insulator weight, lbs.
VS = vertical span, meters (feet).

Example of Vertical Span Calculations for TS Pole Top Assembly (Heavy Loading):

w_c = 1.0776 lbs./ft., see Figure 13-4, S = 22.7 in^3, ϕ = .50 and LF = 1.5 Heavy Loading District,

$$VS = \frac{0.50M_a - (LF)(W_i)(s_c)}{(LF)(w_c)(s_c)}$$

a. $M_a = F_b S$

$M_a = 7400(22.7)/12$

$= 14{,}000\,ft - lbs$

b. $W_i = 50lbs.$

$$VS = \frac{(0.50)(14{,}000) - (1.5)(50)(5.5)}{(1.5)(1.0776)(5.5)}$$

$= 741\,ft.$

Check vertical span for extreme ice with concurrent wind,

w_c = 2.4092 lbs./ft., ϕ = 1.0 and LF = 1.1 for extreme ice with concurrent wind

$$VS = \frac{(1.0)(14{,}000) - (1.1)(50)(5.5)}{(1.1)(2.4092)(5.5)}$$

$= 939\,ft.$

13.4.4 Span Calculations for TSZ Pole Top Assembly: The TSZ structure is a wishbone-type crossarm assembly. It is intended for use on transmission lines where conductor jumping due to ice unloading and/or conductor galloping are problems. The wishbone provides additional vertical and horizontal offset between phases in order to reduce the possibilities of phase-to-phase faulting due to ice unloading or galloping.

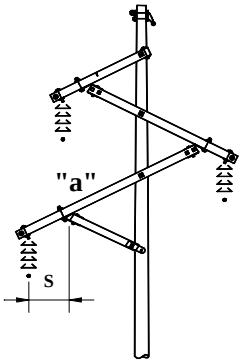


FIGURE 13-6: TSZ-1 POLE TOP ASSEMBLY

Since the crossarms of the wishbone are not horizontal, the vertical span is related to the horizontal span. The maximum vertical load (W_C) the TSZ-1single crossarm assembly can withstand is 3,400 lbs. at any conductor position. By calculating moments at point "a" on the assembly, horizontal and vertical spans are related. Span limited by pole strength are calculated in the same manner as the TP and TS structures.

Example of Span Calculations for Wishbone Pole Top Assemblies**:** Determine the maximum horizontal and vertical spans for the pole top assembly of the 69 kV TSZ-1 pole top assembly (Figure 13-7).

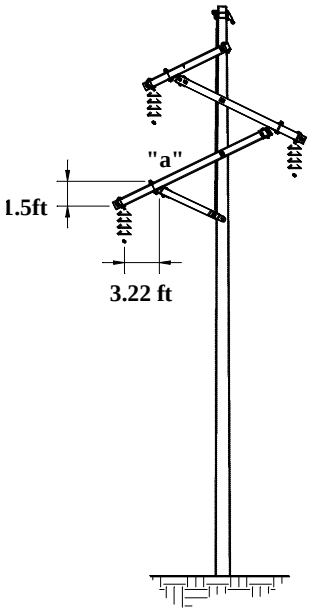


FIGURE 13-7: TSZ-1 EXAMPLE

Given:
Loadings: NESC heavy loading district

Wires
Conductor: 266.8 kcmil, 26/7 ACSR (Partridge)
OHGW: 3/8” H.S.S
Pole: S.Y.P. (70-1)

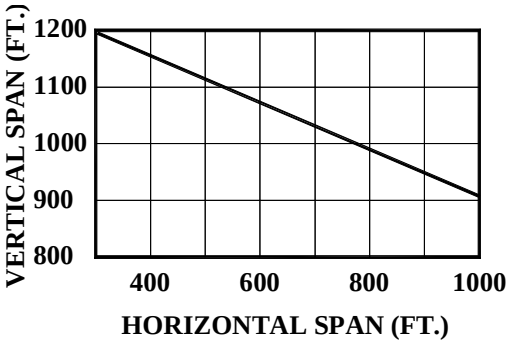


FIGURE 13-8: HS vs. VS FOR TSZ-1

Solution:

Moment capacity of crossarm at "a":

$M_a = W_c(s)$

$M_a = 3{,}400(3.22)$

$= 10{,}950$ ft-lbs.

Horizontal and vertical span:

The relationship between the horizontal and vertical spans is obtained by summing moments about point 'a'.

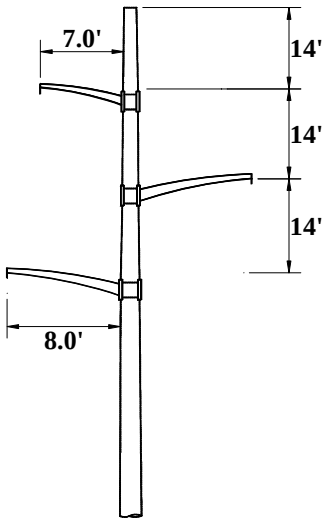
$2.5(.5473)(1.5)HS+1.5(1.0776)(3.22)VS+1.5(50)(3.22) = (0.50)(10{,}950)$ ft-lbs.

$2.05HS+5.21VS = 5234$ ft-lbs.

For HS = VS, Span = 720 ft. See Figure 13-8 for application chart.

13.4.5 Span Calculations for TU-1 Pole Top Assembly: These assemblies have steel upswept arms. With these arms, vertical spans are related to horizontal spans and a graph can be made to relate horizontal and vertical spans. Spans limited by pole strength are calculated in the same manner as the TP and TS structures.

Example of Span Calculations for Steel Davit Arm Construction**:** For the 138 kV structure in Figure 13-9, plot the horizontal versus vertical span for steel davit arms.



Given:

Loadings:	NESC Heavy Loading High Wind 19 psf on the wires
Wires:	
Conductor:	477 kcmil, 26/7 ACSR
OHGW:	3/8" H.S.S
Pole:	S.Y.P. (70-1)

Conductor loads:	Heavy Ldg	High wind	EI&W
Transverse	0.6193	1.3585	0.8808
Vertical	1.5014	0.6570	2.4092

Manufacturers catalog data for crossarms:

Rated Ultimate Vert. load (W_c)	s, length	R, rise
3000	8.0	2.7
3000	7.0	2.5

Weight of insulators (W_i): 102 lbs.

FIGURE 13-9: TU-1 STRUCTURE

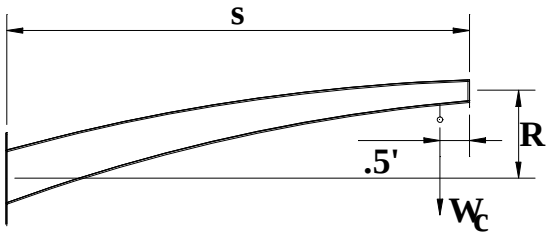


FIGURE 13-9a: DAVIT

Solution:

For the 8.0' davit arm, the moment capacity of the arm at the pole (Figure 13-9a):

$$M_a = W_c(s) = (3000)(8.0) = 24{,}000 \text{ ft-lbs.}$$

An equation for the vertical and horizontal spans can be developed. Since the arm is steel, a strength factor (ϕ) of 1.0 is used.

$$2.5(0.6193)(2.7)HS+1.5(1.5014)(8.0)VS+1.5(102)(8.0) = (1.0)(24{,}000) \text{ ft-lbs.}$$
$$4.1803HS+18.017VS = 22{,}776 \text{ ft-lbs.}$$

For the 7.0' davit arm, the moment capacity of the arm at pole:

$$M_a = W_c(s) = (3000)(7.0) = 21{,}000 \text{ ft-lbs}$$

An equation for the vertical and horizontal spans can be developed:

$$2.5(0.6193)(2.5)HS+1.5(1.5014)(7.0)VS+1.5(102)(7.0) = (1.0)(21{,}000) \text{ ft-lbs.}$$
$$3.87HS+15.77VS = 19{,}929 \text{ ft-lbs.}$$

In this example for the NESC heavy loading district loads, the magnitude of the vertical span is not sensitive to the horizontal span (as shown in Figure 13-10). For horizontal spans between 400 and 1000 feet, the vertical span for the 8 foot arm as well as the 7 foot arm should be limited to 1018 feet (for design purposes, use 1000 feet). Spans limited by the extreme winds are not a factor in this example.

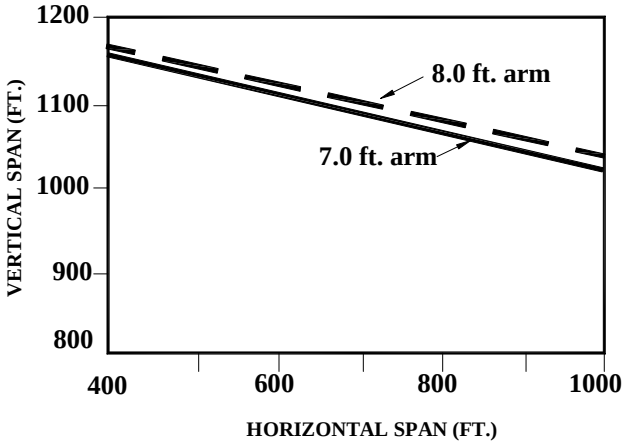


FIGURE 13-10: VS vs. HS FOR TUS-1 STRUCTURE OF EXAMPLE 13-3

13.5 Design Calculations for Wood H-Frame Structures

13.5.1 General: There are various techniques available for analysis of H-frame structures:

- Classical indeterminate structural analysis.
- Matrix methods of structural analysis.
- Approximate methods (explained in this section and subsequent sections).

In analyzing a statically indeterminate structure by approximate procedures, one assumption is made for each degree of indeterminacy. These assumptions are based on logical interpretations of how the structure will react to a given loading. For the H-frame with knee and V-braces, we can assume that the structure will behave as shown in Figure 13-11.

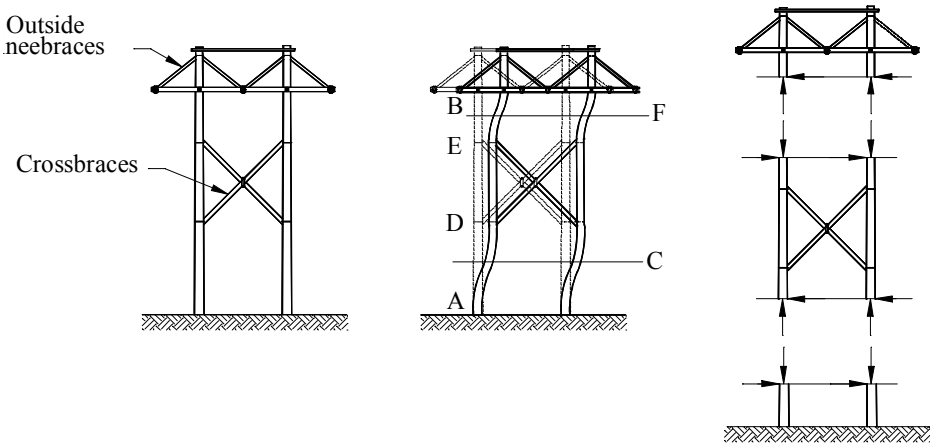
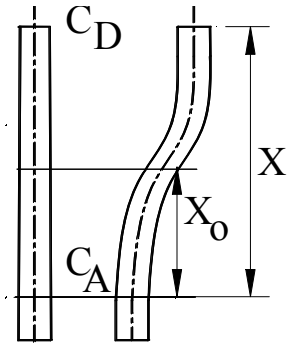


FIGURE 13-11: ASSUMED H-FRAME BEHAVIOR

At some point in the poles, there will be an inflection point (a point of zero moment). If the pole or column is uniform in cross section, it is common to assume that the inflection point is located midway between points of bracing, shown as a dotted line in Figure 13-11. However, since the pole is tapered, the following relationship may be used to determine the location of the inflection point (see Figure 13-12, Equation 13-10 and Appendix H for application chart).



$$\frac{x_o}{x} = \frac{C_A\left(2C_A + C_D\right)}{2\left(C_A{}^2 + C_A C_D + C_D{}^2\right)} \qquad \text{Eq. 13-10}$$

where:

C_A = circumference at base
C_D = circumference at top

FIGURE 13-12: LOCATION OF POINT OF CONTRAFLEXURE

By applying the same reasoning, the inflection point can be located on the other column. Locating the inflection point on each column, and hence the point of zero moment, entails two assumptions for the frame. Since the frame is statically indeterminate to the third degree, a third assumption has to be made. A common third assumption is that the shear in the columns is

distributed equally at the inflection points. The shear in the columns is equal to the horizontal force on the structure above the level under consideration.

For a less rigid support, the inflection point moves toward the less rigid support. Two conclusions can be made:

- For a pole rotating in the ground, the inflection point "C" below the crossbraces, is lowered. The lowering of the inflection point inreasing the moment induced in the pole at the connection of the lower crossbrace. Since the amount of rotation of a base is difficult to determine, the usual design approach is to always assume a rigid base.

- For H-frames with outside kneebraces only, the point of inflection 'F'above the crossbrace (shown in Figure 13-11) is higher than the point of inflection for four kneebraces. This higher point of inflection increases the moment in the pole at the upper crossbrace-pole connection. For the H-frame with outside kneebraces only, the designer may make one of two assumptions:

  (1) When determining induced moments in the poles, the outside kneebraces are ignored and no point of inflection exists between the crossbrace and the crossarm. This is a conservative assumption and assumes that the purpose of outside braces is to increase vertical spans only.

  (2) It can be assumed that the point of inflection occurs at the crossarm. This assumption will be used in the equations and examples which follow.

13.5.2 <u>Crossbraces</u>: The primary purpose of wood X-bracing for H-frame type structures is to increase horizontal spans by increasing structure strength. Additional benefits achieved by crossbracing include possible reduction of right-of-way costs by eliminating some guys and reduction of lateral earth pressures. For an efficient design, several calculations should be made in order to correctly locate the crossbrace.

The theoretical maximum tensile or compressive load which the wood crossbrace will be able to sustain will largely be dependent on the capacity of the wood brace to sustain a compressive load. Drawing TM-110, X-brace Assembly of Bulletins 1728F-810 and 811, is to be used for the 115, 138, 161 kV, and 230 kV tangent structures. The crossbrace dimension is 3-3/8" x 4-3/8" for the 115 kV structure, 3-3/8" x 5-3/8" for 138 kV and 161 kV structures. The dimensions of this X-brace for the TH-230 structure are 3-5/8" x 7-1/2" (minimum).

The maximum compressive load which a wood X-brace is able to sustain is determined by:

$$P_{cr} = \frac{A(\pi^2)E}{\left(\frac{k\ell}{r}\right)^2} \qquad \text{Eq. 13-11}$$

where:

P_{cr} = maximum compressive load, lbs.
A = area, in^2
E = modulus of elasticity, psi.
$k\ell$ = effective unbraced length, in.
r = radius of gyration, in. which will give you the maximum $k\ell / r$ ratio; $k\ell$ and r must be compatible for the same axis

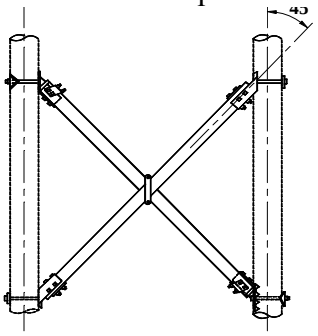


FIGURE 13-13: CROSSBRACE

For an assumed 1 foot diameter pole, the following theoretical values apply:

TABLE 13-3
CROSSBRACE CAPACITIES

Crossbrace	A Area (in^2)	r Least Radius of Gyration (in.)	L Distance C_L to C_L of Poles (ft.)	0.5L/0.707 less 1' for Pole Dia., (in.)	kl / r	P_{cr} for E = 1.8 x 10^6 (lbs.)
TM-110						
3-3/8" x 4-3/8"	14.77	0.9743	12.5	97.6	100.2	26,100
3-3/8" x 5-3/8"	18.14	0.9743	15.5	123.1	126.3	20,200
TM-110A						
3-5/8" x 7-1/2"	27.19	1.05	19.5	157	149.5	21,600

The calculations included in Table 13-3 do not reflect the capacity of the hardware. RUS Specifications for Double Armed and Braced Type Crossarm Assemblies (138 kV and 161 kV), and RUS Specifications for Double Armed and Braced Type Crossarm Assemblies (230 kV) require X-braces to withstand a tension or compression loading of 20,000 lbs. This ultimate value correlates with the above theoretical ultimate loads in the table. It is recommended that 20,000 lbs. (ultimate) be used for design purposes, since this value assures one that the crossbrace will sustain the indicated load.

For the 115 kV structure (TH-1AA) it is recommended that 20,000 lbs. be used as the ultimate load the crossbrace is able to sustain. The hardware for the crossbrace is the same as the hardware used with 138 kV and 161 kV structures.

13.5.3 V-Braces: The primary purpose of two V-braces on the outside of the poles is to increase vertical spans. Two V-braces on the inside will increase horizontal spans. Four V-braces increase both horizontal and vertical spans. The various bracing arrangements and their designations for 161 kV structures are shown in Figure 13-14.

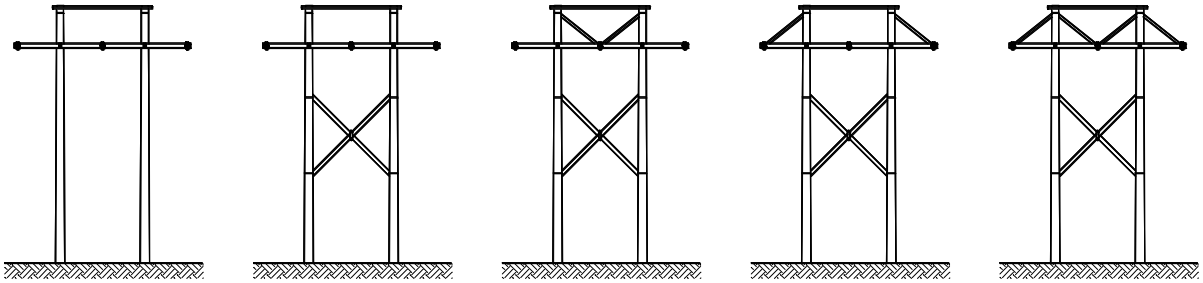


FIGURE 13-14: POLE TOP BRACING ARRANGEMENTS
('X' added to the pole top assembly nomenclature refers to crossbrace)

RUS Specifications for Double Armed and Braced Type Crossarm Assemblies (138 kV and 161 kV) specifies the following minimum strength requirements for the various pole top assemblies:

Maximum vertical load (at any conductor position)	
TH-10	8,000 lbs.
TH-10VO	14,000 lbs.
TH-10V4	14,000 lbs.

Maximum transverse conductor load (total)

TH-10VO	15,000 lbs.
TH-10V4	15,000 lbs.

Maximum tension or compression in V-brace
20,000 lbs.

RUS Specifications for Double Armed and Braced Type Crossarm Assemblies (230 kV) specifies the following minimum strength requirements for the TH-230 pole top assembly:

Maximum vertical load (at any conductor position)

TH-230	10,000 lbs.

Maximum transverse conductor load (total)

TH-230	15,000 lbs.

Maximum tension or compression in V-brace

TH-230	20,000 lbs.

When determining maximum vertical and horizontal spans as limited by H-frame top assemblies, the above minimum strengths may be used as guidance.

13.5.4 Structure Analysis of H-frames: Equations 13-16 to 13-22 are used for calculating forces in the various members of H-frame structures. As part of the structural analysis, span limitations due to strength of the pole top assembly (Equations 13-12 to 13-15) should be considered and suggested methods follow. Appropriate load factors and strength factors should be applied in the respective equations.

Outside V-Braces**:** An H-frame structure with two outside V-braces in figure 13-14 (and shown in greater detail in Figure 13-19) needs further explanation. A structure with two outside V-braces has less rigidity above the crossbrace than a structure with than four V-braces. The location of the point of contraflexure is difficult to determine. Equation 13-10, which calculates the moment (M_E) at the top of the crossbrace assumes that the point of contraflexure exists at the crossarm. However, when using Equation 13-12 to determining span limitations due to strength of the pole top assembly, a point of contraflexure is assumed between the top of the crossbrace and the crossarm.

The maximum vertical span is determined for the maximum horizontal span.

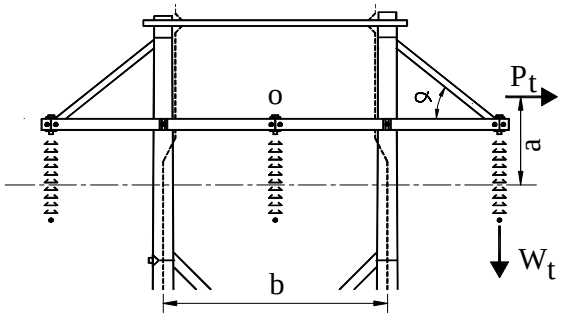


FIGURE 13-15: POLE TOP ASSEMBLY WITH TWO OUTSIDE BRACES

Ultimate force in the brace is:

$$\frac{(LF)W_t}{\sin\alpha} + \frac{(LF)P_t(a)}{(b)\sin\alpha} \le (\phi)20{,}000 \cdot lbs \qquad \text{Eq. 13-12}$$

where:

W_t = total vertical load at the phase wire, locations, lbs.,
$W_t = VS(w_c)+W_i$,
VS = vertical span, ft.
w_c = weight load per foot of conductor, lbs./ft.
W_i = total weight of the insulators, lbs.

P_t = total transverse load, lbs.
$P_t = (HS)(3p_c+2p_g)$ where
HS = horizontal span, ft.
p_c = wind load per foot of conductor, lbs./ft.
p_g = wind load per foot of overhead ground wire, lbs./ft.

a = distance from the point of contraflexure to equivalent force, ft.
b = distance between poles, ft.
LF = load factor
α = angle the brace makes with the crossarm

Two Inside V-Braces**:** Pole bending moment, uplift, and force in the X-brace may be calculated in the same manner as when four braces are used. Crossarm strength controls the maximum vertical span.

Force in the braces is:

$$\frac{(LF)W_t}{2\sin\alpha} + \frac{(LF)P_t(a)}{(b)\sin\alpha} \le (\phi)20{,}000.lbs \qquad \text{Eq. 13-13}$$

Crossarm bending moment, $(\phi)M_o$ is:

$$(\phi)M_o = \frac{(LF)W_t(b)}{2} \qquad \text{Eq. 13-14}$$

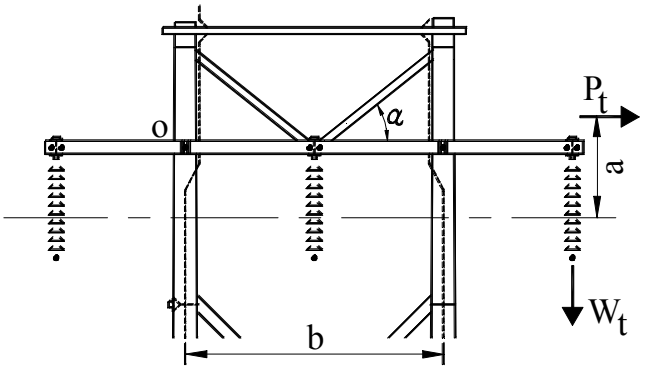


FIGURE 13-16: POLE TOP ASSEMBLY WITH INSIDE BRACES

Four V-Braces**:** The following equations can be used to determine the maximum vertical span as limited by four V-braces, given the maximum horizontal span:

For four V-braces, force in the outside braces is:

$$\frac{(LF)W_t}{\sin\alpha} \le (\phi)20{,}000\,lbs \qquad \text{Eq. 13-15}$$

Force in the inside braces is:

$$\frac{(LF)W_t}{2\sin\alpha} + \frac{(LF)P_t(a)}{(b)\sin\alpha} \le (\phi)20{,}000\,lbs \qquad \text{from Eq. 13-13}$$

13.5.5 Abbreviations: In Equations 13-16 to 13-23, all units should be consistent. The following abbreviations apply:

D_e	=	embedment depth
F	=	wind pressure on a cylindrical surface, psf
F_s	=	presumptive skin friction value, psf
HS	=	horizontal span, ft.
M_a	=	moment capacity of crossarm
M_n	=	moment capacity at the indicated location 'n', ft-lb. includes moment reduction due to bolt hole, i.e., $M_n = M_{cap}$-M_{bh}.
LF	=	load factor (see Chapter 11 of this bulletin)
Q_u	=	ultimate bearing resistance of the soil, psf
R_n	=	reaction at the indicated location,"n," lbs.
U	=	dummy variable
V	=	dummy variable
V_n	=	induced axial force at the indicated location, lbs.
VS	=	vertical span, ft.
W_c	=	weight of conductors (plus ice, if any),lbs.
W_g	=	weight of OHGW (plus ice, if any),lbs.
W_i	=	total weight of the insulators
$W_{l\text{-}p}$	=	weight of a line person
W_p	=	weight of pole, lbs.
W_t	=	total weight equal to weight of conductors (plus ice, if any, W_C) plus weight of insulators,W_i.
W_1	=	total resistance due to skin friction around the embedded portion of the pole, lbs.
W_2	=	total bearing resistance of the soil, lbs.
X	=	dummy variable
Y	=	dummy variable
a	=	distance from P_t to the point of contraflexure above the crossbrace for an H-frame structure with pole top bracing. Ft.
b	=	spacing of the poles of an H-frame, ft.
d_{avg}	=	average diameter of pole between groundline and butt, ft.
d_{bt}	=	diameter of pole at butt, ft.
d_n	=	diameter at location "n," ft.
d_t	=	diameter of pole at top, ft.

f_s = calculated skin friction value, psf
h_n = length as indicated, ft.
P_t = total horizontal force per unit length due to wind on the conductors and overhead ground wire, lbs./ft.
s_n = distance as shown, ft.
w_c = weight per unit length of the conductors (plus ice, if any), lbs./ft.
w_g = weight per unit length of overhead ground wire (plus ice, if any), lbs./ft.
ϕ = strength factor (see Chapter 11 of this bulletin)

13.5.6 <u>Equations for Structure 1 (Figure 13-17)</u>: For this structure, the horizontal span is reduced by 10 % to take into account P-delta (P-δ)moments (i.e. 0.90 in Equation 13-16). For a more detailed analysis, see Equation 13-1 for single poles.

$$HS_A = \left((\phi)M_A - \frac{(LF)(F)(h)^2(2d_t + d_a)}{6} \right) / \left(\frac{(LF)(p_t)(h_1)}{2} \right)(0.90) \qquad \text{Eq. 13-16}$$

$$R_A = (LF)(W_g + 3/2W_t + W_p) \qquad \text{Eq. 13-17}$$

$$VS = \frac{(\phi)M_a - (LF)(W_i)(s)}{w_c(s)(LF)} \qquad \text{Eq. 13-18}$$

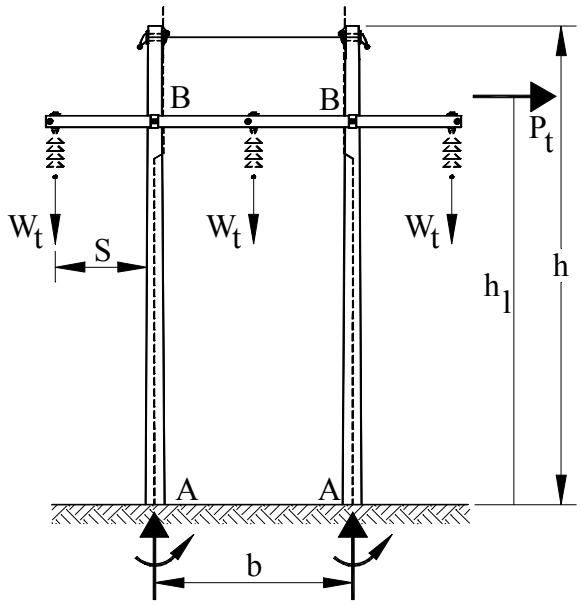


FIGURE 13-17: STRUCTURE 1

13.5.7 Equations for Structure 2 (Figure 13-18):

$$HS_B = \left((\phi) M_B - \frac{(LF)(F)(y_1)^2 (2d_t + d_b)}{6} \right) / (LF)(p_g)(y_1) \qquad \text{Eq. 13-19a}$$

$$HS_E = \left((\phi) M_E - \frac{(LF)(F)(y)^2 (2d_t + d_e)}{6} \right) / \frac{(LF)(p_t)(y_o)}{2} \qquad \text{Eq. 13-19b}$$

$$HS_D = \left((\phi) M_D - \frac{(LF)(F)(h - x_o)(x_1)(d_t + d_c)}{2} \right) / \frac{(LF)(p_t)(x_1)}{2} \qquad \text{Eq. 13-19c}$$

$$HS_A = \left((\phi) M_A - \frac{(LF)(F)(h - x_o)(x_o)(d_t + d_c)}{2} \right) / \frac{(LF)(p_t)(x_o)}{2} \qquad \text{Eq. 13-19d}$$

For crossbrace:

$$HS_x = \left((\phi) 28{,}300(b) - 2(LF)(F)(h - x_o)^2 (2d_t + d_c)/6 \right) / (LF)(p_t)(h_2) \qquad \text{Eq. 13-19e}$$

For uplift:

$$HS(p_t)(h_2) - VS(w_g)(b) - 1.5VS(w_c)(b) = W_1(b) + W_p(b) + X - Y \qquad \text{Eq. 13-19f}$$

For bearing:

$$HS(p_t)(h_2) + VS(w_g)(b) + 1.5VS(w_c)(b) = W_2(b) - W_p(b) + X - Y + (w_1)(b) \qquad \text{Eq. 13-19g}$$

where:

$$W_1 = F_s (D_e)(d_{avg})\pi / S.F. \qquad \text{Eq. 13-19h}$$

$$W_2 = (\pi \, d_{bt}{}^2 / 4)(Q_u) / S.F. \qquad \text{Eq. 13-19i}$$

$$X = (F)(h - x_o)(d_t + d_c)(x_o) \qquad \text{Eq. 13-19j}$$

$$Y = 2(F)(h)^2 (2d_t + d_a)/6 \qquad \text{Eq. 13-19k}$$

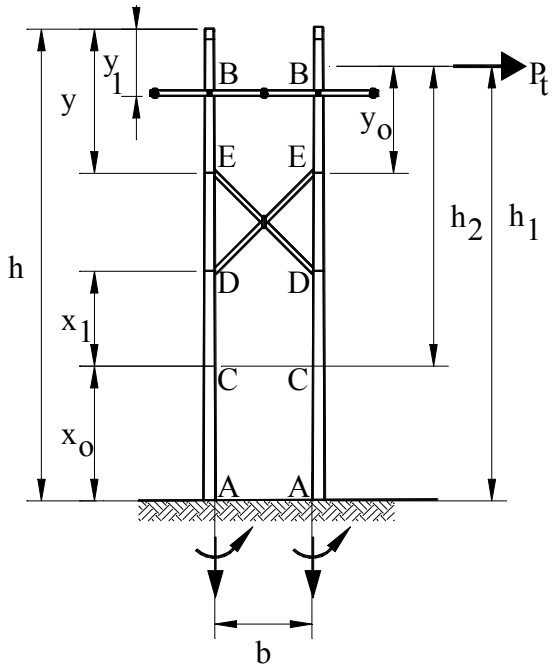


FIGURE 13-18: STRUCTURE 2

13.5.8 Equations for Structure 3 (Figure 13-19):

$$HS_E = \left((\phi) M_E - \frac{(LF)(F)(y_1)(z)(d_t + d_b)}{2} \right) / \frac{(LF)(p_t)(z)}{2} \qquad \text{Eq. 13-20}$$

HS_D, HS_A = same as structure #2.

For crossbrace, uplift and bearing: same as structure #2

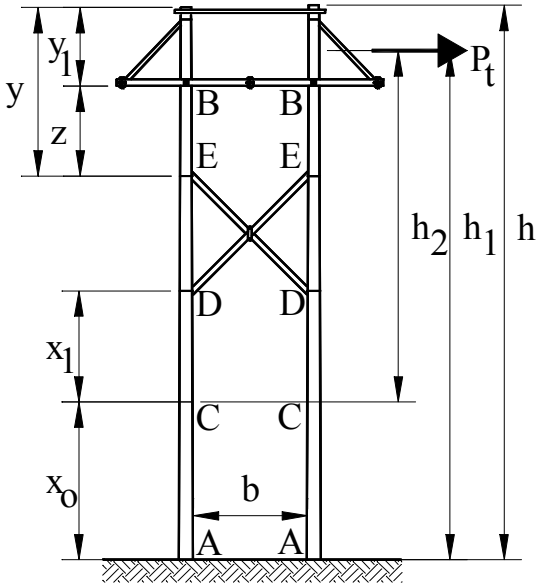


FIGURE 13-19: STRUCTURE 3

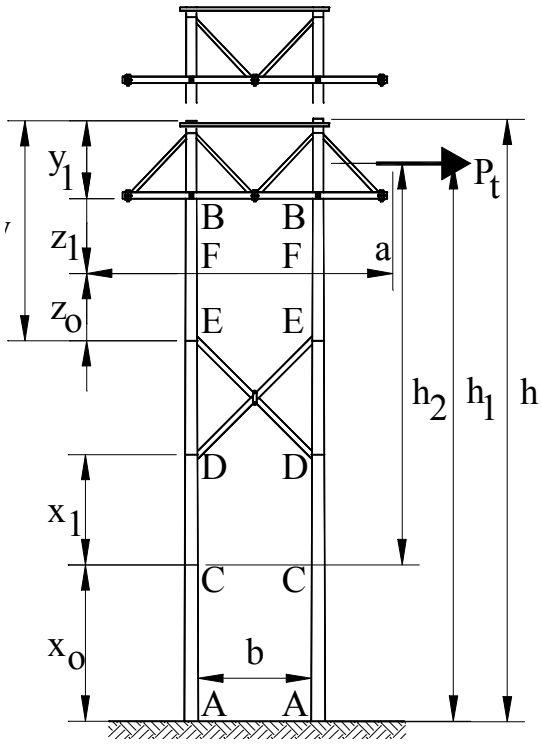


FIGURE 13-20: STRUCTURE 4

13.5.9 Equations for Structure 4 (Figure 13-20):

$$HS_B = \left((\phi) M_B - \frac{(LF)(F)(y - z_o)(d_t + d_f)(z_1)}{2} \right) / \frac{(LF)(p_t)(z_1)}{2} \qquad \text{Eq. 13-21a}$$

$$HS_E = \left((\phi) M_E - \frac{(LF)(F)(y - z_o)(d_t + d_f)(z_o)}{2} \right) / \frac{(LF)(p_t)(z_o)}{2} \qquad \text{Eq. 13-21b}$$

HS_D, HS_A = same as structure #2.

For uplift and bearing: same as structure #2.

For crossbrace:

$$HS_x = \left((\phi) 28{,}300 (b) - U + V \right) / \left[(LF)(p_t)(h_2 - a) \right] \qquad \text{Eq. 13-21c}$$

where:

$$U = 2(LF)(F)(h - x_o)^2 (2d_t + d_c)/6 \qquad \text{Eq. 13-21d}$$

$$V = 2(LF)(F)(y - z_o)^2 (2d_t + d_f)/6 \qquad \text{Eq. 13-21e}$$

13.5.10 Equations for Structure 5 (Figure 13-21):

For crossbrace:

$$HS_x = \left((\phi)56{,}500(b) - 2(LF)(F)(h - x_o)^2(2d_t + d_c)/6\right)/[(LF)(p_t)(h_2)] \qquad \text{Eq. 13-22}$$

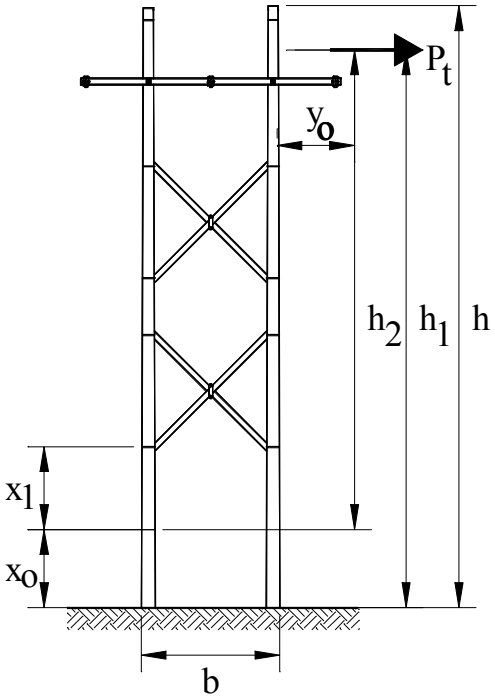


FIGURE 13-21: STRUCTURE 5

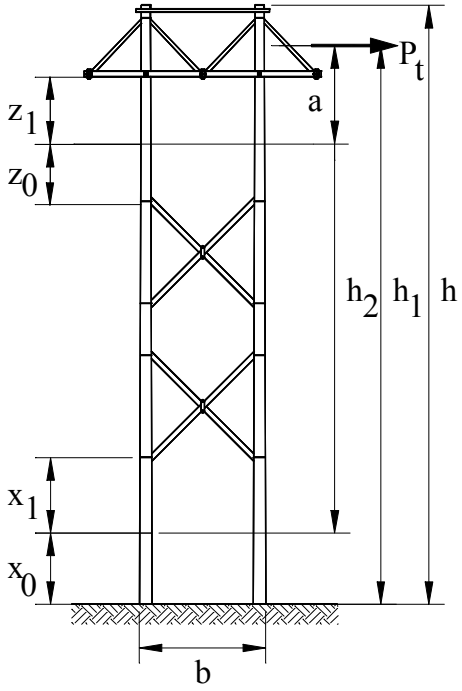


FIGURE 13-22: STRUCTURE 6

13.5.11 Equations for Structure 6 (Figure 13-22):

For crossbrace:

$$HS_x = \left((\phi)56{,}500(b) - U + V\right)/[(LF)(p_t)(h_2 - a)] \qquad \text{Eq. 13-23}$$

where:

U, V = same as structure #4

13.6 Example of an H-frame Analysis: For the 161 kV structure shown in Figure 13-23, determine the horizontal span based on structure strength and uplift and plot the horizontal versus vertical span for the pole top assembly.

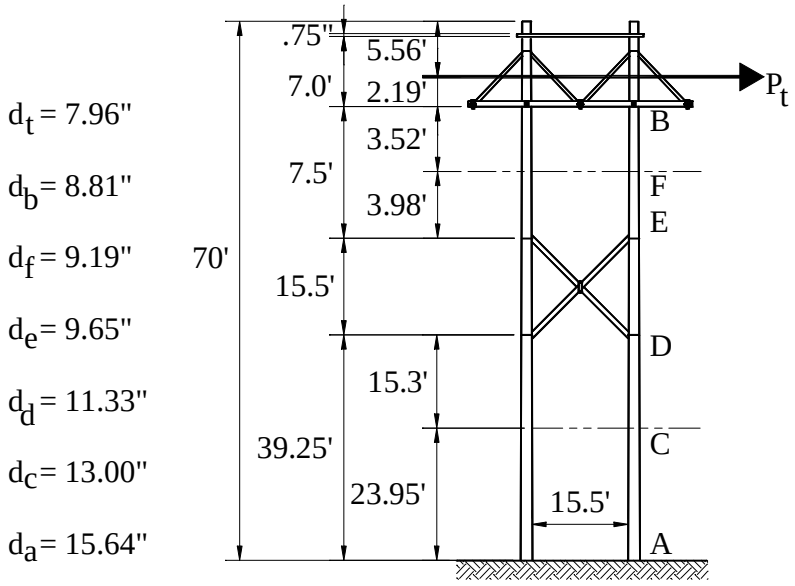


FIGURE 13-23: EXAMPLE OF AN H-FRAME

13.6.1 Given:

NESC heavy loading	
High winds -	19 psf on the wires and 22 psf on the structure
Heavy ice -	1" radial ice
Extreme ice with concurrent wind	1" radial ice with 4 psf wind

Pole:	Douglas fir 80-2
Conductor:	ACSR 795 kcmil 26/7
OHGW:	7/16 E.H.S.
Ruling Span:	800 ft.

Conductor Loads	Heavy Ldg District	High Wind	Heavy Ice	EI&W
Transverse Loads	0.7027 lbs./ft.	1.7543 lbs./ft.	0	1.0360
Vertical Loads	2.0938 lbs./ft.	1.0940 lbs./ft.	3.7154 lbs./ft.	3.7154
Tension	10,400 lbs.	---	14,000 lbs	

OHGW Loads	Heavy Ldg District	High Wind	Heavy Ice	EI&W
Transverse Loads	0.4783 lbs./ft.	0.6888 lbs./ft.	0	.8116
Vertical Loads	0.9803 lbs./ft.	0.3990 lbs./ft.	2.1835 lbs./ft.	2.1835
Tension	5,900 lbs.	---	7,500 lbs.	

Soil: Average. Presumptive skin friction (ultimate) of 250 psf for predominantly dry soil areas and using native backfill; 500 psf when aggregate backfill is used.

13.6.2 Solution for Heavy Loading District Loads: Maximum horizontal span based on structure strength:

a. Equivalent load p_t :

$$p_t = 2p_g + 3p_c$$
$$= 2(0.4783) + 3(0.7027)$$
$$= 3.065 \ lbs/ft.$$

b. Determine location of equivalent load p_t :

$$\text{Distance from top} = \frac{2p_g(0.75) + 3p_c(7.75)}{p_t}$$
$$= 5.56 ft.$$

c. Determine location of x_o, x_1, z_0 and z_1 for the X - brace location shown.

All diameters, d_n, determined by Appendix F, and ratio x_o/x_1 or z_o/z determined by Appendix H.

For x_o, x_1 :

$$\frac{d_d}{d_a} = \frac{11.33}{15.64} = 0.72$$
$$\therefore \frac{x_o}{x} = 0.61$$
$$x_o = 0.61(39.25)$$
$$x_o = 23.9 ft.$$
$$x_1 = 15.3 ft.$$

and $d_c = 13.0 \ in.$

For z_o, z_1 :

$$\frac{d_d}{d_e} = \frac{8.81}{9.65} = .91$$
$$\therefore \frac{z_o}{z} = 0.53$$
$$z_o = 0.53(7.5)$$
$$z_o = 3.98 ft.$$
$$z_1 = 3.52 ft.$$

and $d_f = 9.19 \ in.$

d. Find the horizontal span limited by pole strength at B (see Figure 13 - 23) using Equation 13 - 21a :

$$HS_B = (\phi)M_B - \frac{(LF)(F)(y - z_o)(d_t + d_f)(z_1)}{2} / \frac{(LF)(p_t)(z_1)}{2}$$

a. $M_B = 44{,}700\, ft - lbs.$

b. $$HS_B = \left((0.65)44{,}700 - \frac{2.5(4)(15.25 - 3.98)(0.663 + 0.766)(3.52)}{2} \right) / \left(\frac{2.5(3.065)(3.52)}{2} \right)$$

$= 2{,}133\, ft.$

e. Horizontal span limited by pole strength at E :

$$HS_E = (\phi)M_E - \frac{(LF)(F)(y - z_o)(d_t + d_f)(z_o)}{2} / \frac{(LF)(p_t)(z_o)}{2}$$

a. $M_E = M_{cap} - M_{bh}$

$M_E = 58{,}800 - 8{,}400\, ft. - lbs.$

$M_E = 50{,}400\, ft. - lbs$

(M_{bh} from Appendix F)

b. $$HS_E = \left((0.65)(50{,}400) - \frac{2.5(4)(15.25 - 3.98)(0.663 + 0.766)(3.98)}{2} \right) / \left(\frac{2.5(3.065)(3.98)}{2} \right)$$

$= 2{,}127\, ft.$

f. For horizontal span limited by pole strength at locations D and A, similar calculations can be made. The results are as follows :

$HS_D = 811\, ft.$

$HS_A = 1664\, ft.$

g. For horizontal span limited by strength of the crossbrace :

$$HS_X = ((\phi)28{,}300(b) - U + V) / [(OLF)(p_t)(h_2 - a)]$$

where :

$$U = 2(LF)(F)(h - x_o)^2 (2d_t + d_c) / 6$$

$$V = 2(LF)(F)(y - z_o)^2 (2d_t + d_f) / 6$$

$$U = 2(2.5)(4)(70 - 23.9)^2 (2(0.663) + 1.083) / 6$$

$= 17{,}065\, ft - lbs.$

$$V = 2(2.5)(4)(15.25 - 3.98)^2 (2(0.663) + .766) / 6$$

$= 885\, ft - lbs.$

$$HS_X = [(0.65)28{,}300(15.5) - 17{,}065 + 885] / [(2.5)(3.065)(34.78)]$$

$= 1009\, ft.$

13.6.3 Solution for Heavy Loading District Loads - Maximum span limited by pole top assembly follows:

a. From Equation 13 - 15.

$$\frac{(LF)W_t(VS)}{\sin\alpha} \le (\phi)20{,}000.lbs$$

$$VS = \frac{10{,}000\sin 39° - 1.5(135)}{2.0938(1.5)}$$

$$= 1938\,ft.$$

b. From Equation 13 - 13 :

$$\frac{(LF)W_c(VS)}{2\sin\alpha} + \frac{(LF)p_t(a)(HS)}{b\sin\alpha} \le (\phi)20{,}000\,lbs.$$

$$\frac{1.5(2.0938)(VS)}{2\sin 39°} + \frac{2.5(3.065)(2.19+3.52)(HS)}{15.5\sin 39°} \le (0.50)20{,}000\,lbs.$$

$$2.49VS + 4.48HS \le 10{,}000\,lbs.$$

(For VS equal to the HS, the vertical span is 1,435 ft.)

13.6.4 Solution for Heavy Loading District Loads - Maximum span limited by uplift follows:

Assume dry native backfill, safety factor of 4.

$$HS(p_t)(h_2) - VS(w_g)(b) - 1.5VS(w_c)(b) = W_1(b) + W_p(b) + X - Y$$

where :

$$W_1 = F_s(D)(d_{avg})\pi / SF$$

$$= 2649\,lbs.$$

W_p = Wt. of one pole and half the weight of pole top assembly and crossbrace.

$$= 4200 + 800/2 = 4600\,lbs.$$

$$X = F(h - x_o)(d_t + d_c)(x_o)$$

$$= 7705\,ft - lbs.$$

$$Y = 2(F)(h^2)(2d_t + d_a)/6$$

$$= 17{,}182\,ft - lbs.$$

The equation is as follows :

$$124.13HS - 63.88VS = 102{,}900$$

(For VS = 0, maximum HS = 830 ft.)

13.6.5 Check for extreme ice and concurrent wind: Span limitations based on pole strength and crossbrace strength is controlled by NESC Heavy Loading conditions. The unit conductor loads when load factors and strength factors accounted for, are greater for the Heavy Loading District load than for the EI&W as shown below:

	NESC > EI&W
Transverse load:	7027(2.5)/.65 > 1.0360/.65 lbs/ft
	2.7027 > 1.5938 lbs/ft.

	NESC > EI&W
Vertical load:	2.0938(1.5)/.65 > 3.7154 lbs/ft
	4.8318 > 3.7154 lbs/ft

13.6.6 Check for Extreme Wind Conditions: Although **s**pan limitations based on pole strength and crossbrace strength is controlled by NESC Heavy Loading conditions, span limitations based on uplift is controlled by the extreme wind condition.

For Dry Native Backfill**:** For an assumed safety factor of 1.5, the following equation result:

222.2HS - 25.4VS = 142,862
(For VS=0, maximum HS=640 ft.)

For Aggregate Backfill**:** For an assumed safety factor of 1.5, the following equation results:

222.2HS - 25.4VS = 252,400
(For VS=0, maximum HS=1,135 ft.)

When considering uplift, it may be prudent to base calculations on the minimum vertical span as limited by insulator swing.

13.6.7 Summary of Span Limitations:

Horizontal Span limits**:**

HS_A = 1664 ft.
HS_D = 811 ft.
HS_E = 2127 ft.
HS_B = 2133 ft.
HS_x = 1009 ft.

Dry native backfill:
For a VS = 0, the HS (limited by uplift) = 640 ft.

Aggregate backfill:
For a VS = 0, the HS (limited by uplift) = 1,135 ft.

Vertical Span limited by Heavy District Loads**:**

$VS_{poletop}$ = 1,435 ft., max. (For VS =HS)

A more efficient design could be achieved by moving the crossbrace.

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14. GUYED STRUCTURES

14.1 Introduction: When a pole structure is guyed, loading on the poles is due to the combined action of vertical and horizontal forces. Vertical forces on the pole include the vertical component of the tension on the guy(s) and the weight of the conductors and insulators. Horizontal forces include transverse due to wire tension at angle structures, horizontal wind forces, and vertical and longitudinal forces from deadending.

Bisector guys are used on small angle structures, whereas head and back guys are used on large angle structures and double deadends. Angles between 10 and 45 degrees may be turned on what is called a "running" angle structure, utilizing bisector guys. Above 45 degrees, unequal stresses will be set up in the conductor where it attaches to the suspension insulator clamp. The sharper the angle or bend in the conductor at the clamp, the more unequal the stresses will be. Any unbalanced longitudinal wire tensions loads on double deadend and large angle structures can be more effectively carried by head and back guys. For large angle structures, the transverse load due to wire tension loads will be a heavy and permanent. Therefore, head and back guys will be more effective in carrying this load.

Figure 14-1 shows a deadend structure in which the conductors are connected to the structure by strain insulators.

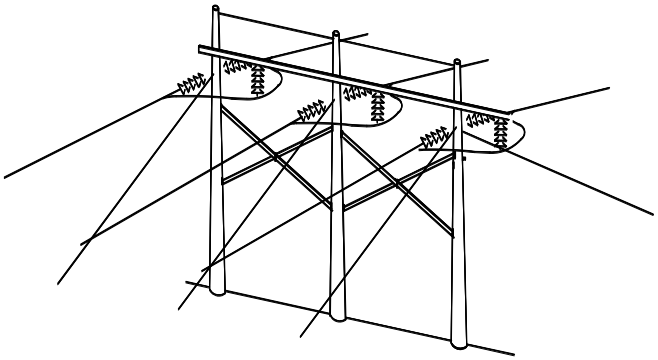


FIGURE 14-1: DEADEND STRUCTURE
(Head and back guys shown)

Deadend structures include:

- Ordinary deadend structures that need only be designed to withstand the load resulting from the difference in tensions of the conductor for the forward and back spans. This condition occurs where there is a change in ruling spans.
- Full deadend structures in which guys and anchors are designed to withstand the resultant load when the conductors are assumed to be broken or slack on one side of the structure. As mentioned in Chapter 10, it is suggested that full deadend structures be located at intervals of five to ten miles to prevent progressive cascading-type failures.

In general for wood structures, guys and anchors should be installed at deadends, angles, long spans where pole strength is exceeded, and at points of excess unbalanced conductor tension. The holding power and condition of the soil (whether wet or dry, packed or loose, disturbed or undisturbed, etc.) and the ability of the pole to resist buckling and deflection should be considered. Unguyed steel and concrete pole structures are sometimes used at angles and deadends to avoid the use of guys. In these cases, careful consideration needs to be made of the structure and foundation design and deflection.

14.2 Load Factors: In Chapter 11, Tables 11-6 and 11-7 give recommended minimum load factors (LF) associated with the design guys and anchors. Table 14-1 summarizes the application of the load factors and strength factors for guys and anchors.

TABLE 14-1
APPLICATION OF LOAD AND STRENGTH FACTORS FOR GUYED STRUCTURES
(GUYS AND ANCHORS)

Loading Districts:						
NESC	(2.50)(a+b)	+	1.65c	=	$G \cos\beta \leq (0.9)G_u \cos\beta$	
Recommended	(2.50)(a+b)	+	1.65c	=	$G \cos\beta \leq (\phi)G_u \cos\beta$	(See table 11-6 of this bulletin for ϕ)
Extreme Winds and Extreme Ice with Concurrent Winds:						
NESC	(1.00)(a+b)	+	1.00c	=	$G \cos\beta \leq (0.9)G_u \cos\beta$	
Recommended	(1.10)(a+b)	+	1.100c	=	$G \cos\beta \leq (\phi)G_u \cos\beta$	(See table 11-7 of this bulletin for ϕ)

Where:

a	=	Transverse wind load on the conductor
b	=	Transverse wind load on the pole
c	=	Transverse component of wire tension load.
A_u	=	Rated anchor capacity
G	=	The calculated force in the guy, considering guy lead. The rated breaking strength of the guy wire (G_u) and the anchor capacity (A_u) multiplied by their respective strength factor must equal or exceed this value.
G_u	=	Rated breaking strength of the guy wire
ϕ	=	Strength factor; see table 11-7 of this bulletin
cosβ	=	Guy slope with horizontal groundline

14.2.1 Longitudinal Strength: Longitudinal strength is applicable to crossings and locations where unequal spans and unequal vertical loadings may occur. Required longitudinal strength of wood tangent structures at crossings is defined by NESC Rule 261A2. The rule states that wood tangent structures which meet transverse strength requirements without guys, shall be considered as having the required longitudinal strength, provided that the longitudinal strength of the structure is comparable to the transverse strength of the structure. If there is an angle in the line, the wood structure will have the required longitudinal strength provided:

- The angle is not over 20 degrees,
- The angle structure is guyed in the plane of the resultant conductor tensions, and
- The angle structure has sufficient strength to withstand, without guys, the transverse loading which would exist if there were no angle at that structure (with the appropriate load factors and strength factors applied).

14.2.2 Distribution Underbuild: Guying and anchors for distribution underbuild are to comply with NESC Grade B provisions. Refer to Chapter 16 for additional information concerning underbuild.

14.3 Clearances: Recommended clearances to be maintained between any phase conductor and guy wires are indicated in Table 14-2. Refer to Chapter 7 for further details.

TABLE 14-2
RECOMMENDED MINIMUM CLEARANCES IN INCHES
FROM CONDUCTOR TO SURFACE OF STRUCTURE OR TO GUY WIRES (Note A)

Nominal Voltage, Phase to Phase,kV	**34.5**	**46**	**69**	**115**	**138**	**161**	**230**
Standard Number of 5-3/4"x10" Insulators on Tangent Structures	**3**	**3**	**4**	**7**	**8**	**10**	**12**
Max. Operating Voltage, Phase to Phase, kV	34.5	46	72.5	120.8	144.9	169.1	241.5
Max. Operating Voltage, Phase to Ground, kV	19.9	26.6	41.8	69.7	83.7	97.6	139.4
Wind Condition	**Clearance, in.**						
NO WIND CLEARANCE							
Min. clearance to guy at no wind (Notes A, B)	19	19	25	42	48	60	71
MODERATE WIND CLEARANCE (based on NESC Rule 235E, Table 235-6)							
Min. clear. to structure at 6 psf of wind (Notes C, D)	9	11	16	26	30	35	50
Min. clear. to jointly used structures and a 6 psf of wind (Notes C, D)	11	13	18	28	32	37	52
Min. clearance to anchor guys at 6 psf (Notes C, D)	13	16	22	34	40	46	64
HIGH WIND CLEARANCE							
Min. clearance to guys at high wind	3	3	5	10	12	14	20

Notes:

(A) If insulators in excess of the standard number for tangent structures are used, the no-wind clearance value given should be increased by 6 in. for each additional bell. For instance, extra insulation in the form of additional insulator bells may be used on steel structures where grounding is a problem or the structures are located in high isokeraunic areas. In these instances, the no wind clearances should be increased. If excess insulators are needed for contamination purposes only, the additional clearance is not necessary

(B) For post insulators, the no-wind clearance to structure or guy is the length of the post insulator.

(C) A higher wind may be assumed if deemed necessary.

(D) The following values should be added as appropriate where the altitude exceeds 3300 feet

Additional inches of clearance per 1000 feet of altitude above 3300 feet:

Nominal Voltage, KV	34.5	46	69	115	138	161	230
Clearance to structure	0	0	0.14	0.43	0.57	0.72	1.15
Clearance to guy	0	0	017	0.53	0.72	0.90	1.44

14.4 Design

14.4.1 Bisector Guys: For structures utilizing bisector guys, the guys have to be designed to sustain the resultant transverse load due to longitudinal wire tension loads in Table 14-1:

$$c = 2\,(T)\,(\sin \theta/2)$$

where:

T = maximum design tension, lbs.
θ = line angle

The transverse load (a) due to wind on the conductors for an angle structure is given as:

$$a = (p)\,(HS)\,(\cos \theta/2)$$

where:

p = wind load in lbs./ft.
HS = horizontal span, ft.
θ = line angle; $\cos \theta/2$ is usually set equal to one

Wind on the structure may be converted to a horizontal force (b) at the point of guy attachment.

14.4.2 Head and Back Guys: Wood pole deadends, double deadends, and large angle structures will normally require head and back guys. For tangent deadends and double deadends, the transverse strength of the structure must be sufficient to carry the appropriate wind load. In some cases, bisector guys or crossbraces may have to be used to meet transverse strength requirements. The tension in the guy should take into account the slope of the guy.

14.5 Pole Strength: Once the tension in the guy wire has been calculated, the compressive strength of the pole should be calculated and checked to see if the pole selected will be adequate for the intended use.

14.5.1 Stability Concept: The selection of structural members is based on three characteristics: strength, stiffness, and stability. When considering a guyed wood, steel or concrete pole, it is important that the designer check the stability of the structure for the expected loadings.

For an example of stability, consider the axial load carrying capabilities of the rods in Figure 14-2. The rod on the left is unquestionably "more stable" to axial loads than the rod on the right. Consideration of material strength alone is not sufficient to predict the behavior of a long slender member. As an example, the rod on the right might be able to sustain 1000 lbs axial load when considering strength (ultimate compressive stress times area), but could only sustain 750 lbs. when considering stability of the system. The rod on the right is more likely to become laterally unstable through sidewise buckling.

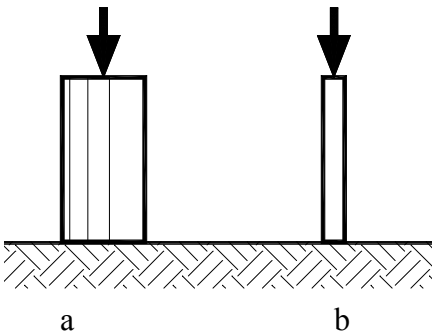


FIGURE 14-2: COMPARISON OF RODS TO SHOW STABILITY CONCEPT

14.5.2 Critical Column Loads: In transmission structures, the guyed pole acts as a column, sustaining axial loads induced in the pole from vertical guy components. The taller the pole, the less load the guyed pole can sustain in compression before the structure becomes "unstable".

Stability of a column can be thought of in one of two ways:

a. The column is unstable when the axial force would cause large lateral defections even when the lateral load was very small.

b. When a column subjected to an axial force, a small deflection may be produced. The column is considered stable if the deflection disappears when the lateral force is removed, and the bar returns to its straight form. If the axial force (P) is gradually increased, a condition is reached in which the straight form of equilibrium becomes unstable and a small lateral force will produce a deflection which does not disappear when the lateral force is removed. The "critical" load is then the axial force which causes buckling or collapses due to any bowing or lateral disturbance.

14.5.3 Calculation of Buckling Loads: For long slender columns, the critical buckling load is determined by the general equation:

$$P_{cr} = \frac{\pi^2 EI}{(k\ell)^2}$$

(P_{cr} is independent of the yield stress of the material).

where:

P_{cr} = critical buckling load, lbs. or kips
E = modulus of elasticity, psi
I = moment of inertia, in^4
$k\ell$ = the effective unbraced length of the column; kl depends on restraint end conditions of the column.

Where for the various end conditions of the column, P_{cr} is idealized in Figure 14-3 below:

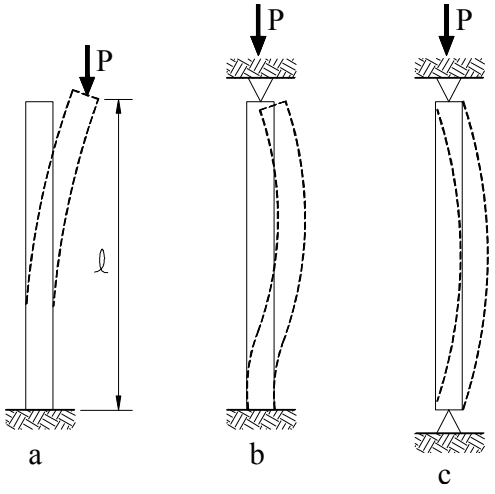


FIGURE 14-3: EFFECTIVE UNBRACED LENGTH FOR VARIOUS END CONDITIONS

Assumptions made in the above calculations:

- The column is perfectly straight initially.
- The axial load is concentrically applied at the end of the column.
- The column is assumed to be perfectly elastic.
- Stresses do not exceed the proportional limit.
- The column is uniform in section properties.

14.5.4 Buckling of Guyed Steel and Concrete Poles: For guyed steel and concrete poles, all the assumptions in paragraph 14.5.3 are violated. As such, the engineer will often ask the pole manufacturer to check the axial capacity of the pole. The engineer must give the pole manufacturer information concerning guy size and strength, yield stress, guy locations, and guy leads. In the case of steel poles, the pole manufacturer should also check the capacity of the guy attachments. It is recommended that in the case of concrete poles, the pole manufacturer should design the guy attachment or at least check the capacity of the pole and attachment when the owner has selected the hardware.

14.5.5 Buckling of Guyed Wood Poles: For a guyed wood poles, all the assumptions in paragraph 14.5.3 are also violated. As such, the engineer must apply appropriate safety factors to account for realistic cases and the variability of wood. Equations for buckling of a wood column with no taper follow:

Conditions	Fixed – Free End Figure 14-3a	Fixed – Pinned End Figure 14-3b	Pinned – Pinned End Figure 14-3c
For a column with no taper	$P_{cr} = \frac{\pi^2 EI}{4\ell^2}$	$P_{cr} = \frac{2\pi^2 EI}{\ell^2}$	$P_{cr} = \frac{\pi^2 EI}{\ell^2}$

One method of calculating the buckling capacity of a tapered wood column was developed by Gere and Carter. This method modifies the critical buckling load as follows:

$$P_{cr} = P_A P^*$$

$$P^* = \left(\frac{d_g}{d_a}\right)^{\alpha}$$

where:

P_A = Critical load for a uniform column with circular cross sections having diameter d (at guy attachment), lbs.

P^* = A multiplier dependent on the end conditions of the column, lbs.

E = Modulus of Elasticity, psi

I_A = Moment of Inertia at the guy attachment, in^4

d_g = Diameter at the groundline, in.

d_a = Diameter at the point of guy attachment, in.

ℓ = Distance from the groundline to the point of guy attachment, in.

α = An exponent that is a function of shape of the column

For tapered round columns, the equations become:

Conditions	Fixed – Free End	Fixed – Pinned End	Pinned – Pinned End
For a tapered column (circular cross section)	$P_{cr} = \frac{\pi^2 EI_A}{4\ell^2}\left(\frac{d_g}{d_a}\right)^{2.7}$	$P_{cr} = \frac{2\pi^2 EI_A}{\ell^2}\left(\frac{d_g}{d_a}\right)^{2.0}$	$P_{cr} = \frac{\pi^2 EI_A}{\ell^2}\left(\frac{d_g}{d_a}\right)^{2.0}$

When using the Gere and Carter method for the NESC district loads with load factors, strength factors between 0.65 to 0.5 respectively are recommended. The resulting safety factor will be between 2.5 and 3.0. For extreme wind loads, it is recommended that strength factors between 0.65 and 0.5 be used, resulting in a safety factor between 1.5 and 2.0. For deadends, lower strength factors (or higher safety factor) should be used.

14.5.6 <u>General Application Notes</u>: For unbraced guyed single poles at small and medium angles structures using bisector guys, certain assumptions are made as to the end constraints. In the direction of the bisector guy, the structure appears to be pinned at the point of the guy attachment and fixed at the base. However, 90° to the bisector guy, the structure appears to be a cantilevered column. Since the conductors and phase wires offer some constraint, the actual end conditions may be assumed to be between fixed-free and fixed-pinned (Figure 14-4a). When checking buckling, it is suggested that the end conditions of pinned-pinned be assumed.

Buckling Mode	End Conditions	
	Bisector Guyed	In-Line Guyed
Longitudinally Transversely	pinned-pinned pinned-fixed	pinned-fixed pinned-fixed

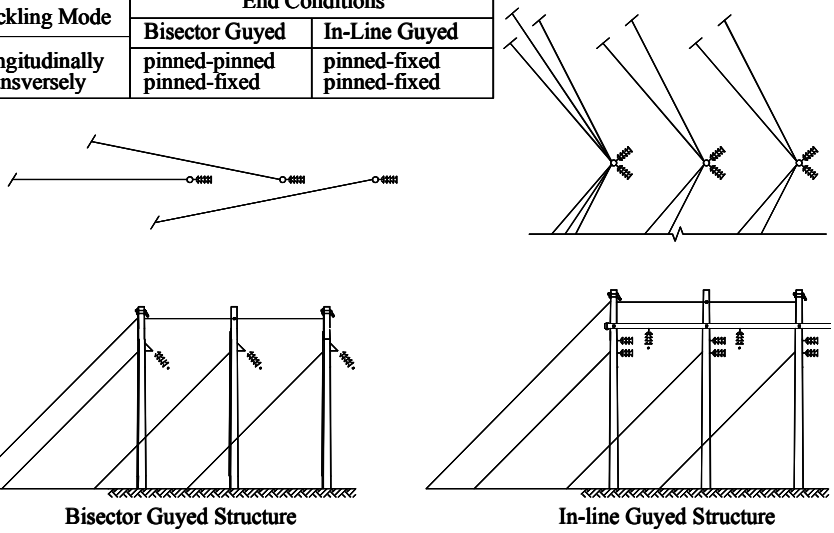


FIGURE 14-4a FIGURE 14-4b

FIGURE 14-4: END CONDITIONS FOR BISECTOR AND IN-LINE GUYED STRUCTURES

For in-line guyed poles at medium angles and large angle deadends, the structure appears to be pinned at the point of guyed attachment and fixed at the base in both directions (Figure 14-4b). For in-line guyed poles at tangent deadends without side guys, it is suggested that fixed-free be assumed.

In many instances, axial loads are applied intermittently along the pole. In Figure 14-5a, the static wire and phase wire are guyed at their respective locations. The axial loads acting on the pole on the left are applied as shown in Figure 14-5b.

In such instances, the usual engineering practice is to assume an unbraced length from the groundline to the lowest guy attachment and the induced axial load in the pole equal to the sum of all axial loads included by the vertical component of the guys.

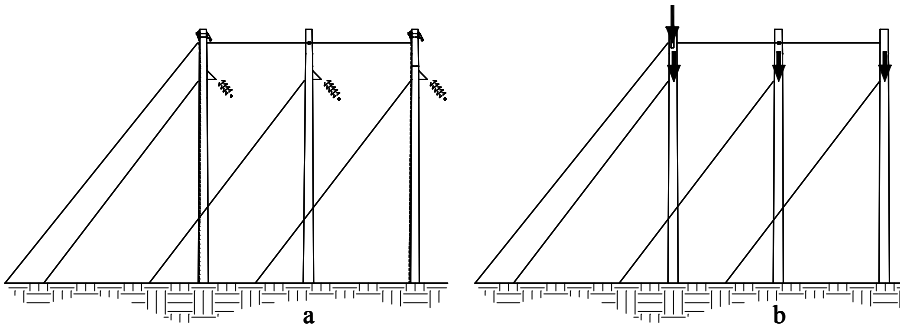


FIGURE 14-5: AXIAL LOADS INDUCED IN A POLE

When the structure is considered to be a double deadend or large angle, the poles, guys, and anchors must sustain the full deadend load with an appropriate load factor. For the tangent double deadend shown in Figure 14-6, the poles must sustain the maximum axial load which might occur if all phase conductors on one side of the structure were removed (see Figure 14-6a and 14-6b). However, to "double account" the loads, as shown in Figure 14-6c would be too conservative.

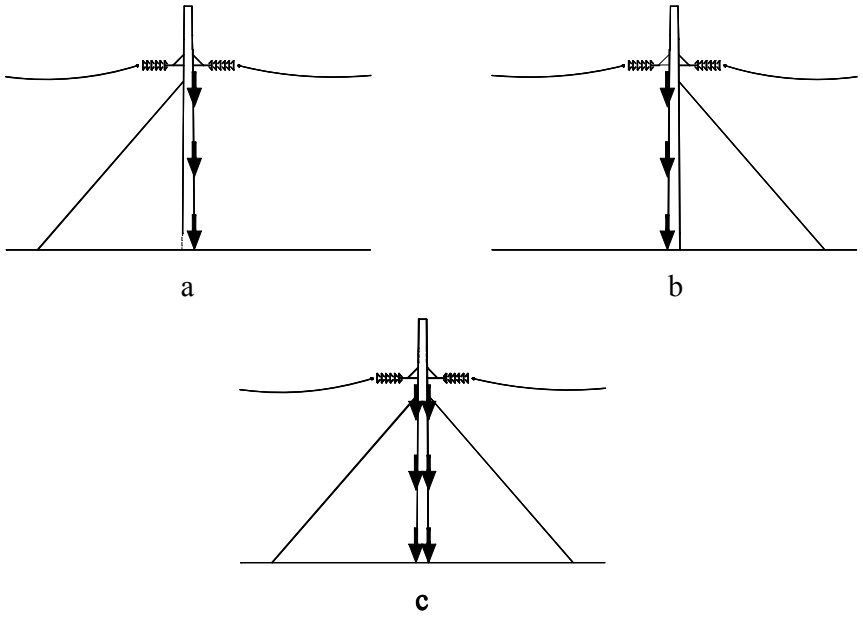


FIGURE 14-6: REPRESENTATION OF AXIAL LOADS (a & b)
AND DOUBLE ACCOUNTING LOADS (c)

For wood pole lines, deadends and large angle structures will often require a higher class pole than that used as the base class pole for the line. Ways to control or reduce the pole class needed at deadends and large angles include:

- Relocate and/or increase the height of tangent structures adjacent to guyed angle and deadends. This would allow the use of shorter poles with guyed structures, and as a result would allow use a lower class pole with no sacrifice in safety.

- Decrease the guy slope. This will decrease the vertical load component pole.

As a note, angle and deadend structures usually comprise about 5 percent of the total structures of a line. Use of conservative safety factors for these critical structures results in a greater overload margin without significantly affecting the total cost of the transmission line.

The engineer should consider guying single pole structures used for small angles, even if the pole has adequate strength to carry the load. Wood poles have a tendency to "creep" with time when subjected to a sustained load. For steel or concrete poles, the engineer should also consider the use of guyed poles at angles or deadend structures. Use of guys will prevent unguyed steel and concrete poles from having large diameters at the groundline and will reduce the cost of foundations.

14.6 Anchors: The holding power of the anchor will largely depend on whether the soil is wet or dry, packed or loose, disturbed or undisturbed. Since soils vary considerably between locations, the holding power of an anchor will also vary considerably.

In areas with a fluctuating water table, the capacity of the anchors should take into account the submerged unit weight of the soil. If at any time the holding power of an anchor is questionable due to variable soil conditions, the anchor should be tested. The primary types of anchors include log anchors, plate anchors, power screw anchors, and rock anchors. The selection of the appropriate anchor will largely depend on the type of soil condition.

14.6.1 Log Anchor Assemblies: The two log anchors in the construction drawings (agency Bulletins 1728F-810 and 811, units TA-2L and 4L) are 8″ x 5′ - 0″ and 8″ x 8′ - 0″, and have an ultimate holding power of 16,000 lbs. and 32,000 lbs. These logs, using one or two anchor rods may be used in combination to provide sufficient holding power for guys. "Average" soil is considered to be medium dense, coarse sand and stiff to very stiff silts and clays. Log anchors should be derated or should not be used in soils of soft clay, organic material, saturated material, or loose sand or silt.

14.6.2 Plate Anchors: The plate anchor assembly TA-3P in Bulletins 1728F-810 and 811, is rated at an ultimate holding power of 16,000 lbs and 24,000 lbs. In firm soils, where the engineer would like to minimize digging, plate anchors may prove economical.

14.6.3 Power Screw Anchors: Screw anchors are being used more often because of their easy installation. They are most appropriate for locations where firm soils are at large depths. The screw anchor assembles TA-2H to TA-4H of Bulletins 1728F-810 and 811 should be installed per manufacturer's recommendations. In addition to the anchor unit being shown on the plan and profile, the capacity of the screw anchor should also be shown. Screw anchors have a higher safety factor than other types of anchors. This higher safety factor is reflected in Information Bulletin 202-1, "List of Materials Acceptable for Use on Systems of USDA Rural Development Electrification," by a reduced designated ultimate holding capacity (70 percent of the manufacturer's suggested holding capacity).

14.7 Drawings: A summary drawing should be prepared for each line, showing the arrangement of guys for each type of structure to be used. The drawing will greatly facilitate the review of the plan and profile, and simplify the construction of the line.

Guys required for various line angles are based on certain spans. Since actual spans will vary, the guying requirements shown will not be suitable for all conditions. Sometimes, it is desirable to make a guying guide for each angle structure which relates horizontal span to the angle of the line (see the example, paragraph 14.8).

The Guying Guide drawing also shows (1) points of attachment of the guy to the pole, (2) slope of the guys, (3) type of structure, and (4) guys and anchors required.

14.8 Example: Develop guying guides for TH-12 161 kV structure.

14.8.1 Design Parameters

General Loading and Structure Information**:**

NESC Heavy Loading		
Extreme Wind:	19 psf on wires,	22 psf on the structure
Heavy Ice:	1" radial	
Extreme Ice with Concurrent winds	1" radial	4 psf

Pole:	Douglas fir 80-2
Conductor:	795 kcmil 26/7 ACSR
Overhead ground wire:	7/16" E.H.S.
Ruling Span:	800 ft.
Guy Wire:	7/16" E.H.S.

Conductor Loads, lbs/ft:

	Heavy	High Wind	Heavy Ice	EI&W
Transverse	0.7027	1.7543	0	1.0360
Vertical	2.0938	1.0940	3.7154	3.7154
Conductor tensions	10,400 lbs.	NA	12940 lbs.	13240 lbs.

Overhead Ground Wire loads, lbs/ft**:**

	Heavy	High Wind	Heavy Ice	EI&W
Transverse	0.4783	0.6888	0	.8116
Vertical	0.9804	0.3990	2.1835	2.1835
OHGW tensions	5,900 lbs.	NA	7,500 lbs.	7800 lbs.

Guy wire: 7/16" E.H.S.

Ultimate tension (R.B.S.):	20,800 lbs.
Horizontal strength with 1/1 lead:	14,700 lbs.

Anchors: 8,000 lbs. and 16,000 lbs.

Ultimate Capacity:	16,000 lbs. and 32,000 lbs.
Horizontal strength with 1/1 lead:	11,300 lbs. and 22,600 lbs.

Soil: Average, presumptive ultimate bearing capacity approximately equal to 4000 psf.

14.8.2 Solution for Heavy Loading District:

a. Wind on the wires:
   Conductor: a = .7027 (HS) (cos θ/2)
   OHGW: a = .4783 (HS) (cos θ/2)
b. Wind on the pole: b = 143 lbs.
   Here (b) is based on an 80-2 pole with the guy located 60 ft. from the ground. The equivalent horizontal load (b), at this location is determined by Mwp/lever arm.

   b = 8590 ft.-lbs./60 ft.

c. Wire tension loads:
   Conductor: c = 2(10,400) sin θ/2
   OHGW: c = 2(5,900) sin θ/2

d. Equations from Table 14-1 of this bulletin:

   General Equation:
   $2.50(a+b) +1.65c = G\cos\beta \leq .65G_u\cos\beta$ or
   $2.50(a+b) +1.65c = G\cos\beta \leq .65A_u\cos\beta$

   For one conductor:

   $2.50 [(.7027) (HS) (\cos \theta/2) + (143)] + 1.65 [2(10,400) (\sin \theta/2)] \leq .65G_u$ (or A_u) $\cos\beta$
   $358 + (1.757) (HS) (\cos \theta/2) + 34,320 (\sin \theta/2) \leq .65G_u \cos\beta$ or $\leq .65A_u\cos\beta$
   $550 + (2.703) (HS) (\cos \theta/2) + 52,800 (\sin \theta/2) \leq G_u \cos\beta$ or $\leq A_u\cos\beta$

   For one OHGW:

   $2.50 [(.4783) (HS) (\cos \theta/2) + (neg.)] + 1.65 [2(5,900) (\sin \theta/2)] \leq .65G_u$ (or A_u) $\cos\beta$
   $(1.196) (HS) (\cos \theta/2) +(19,470) (\sin \theta/2) \leq .65G_u \cos\beta$ or $\leq .65A_u\cos\beta$
   $(1.840) (HS) (\cos \theta/2) +(29,954) (\sin \theta/2) \leq G_u \cos\beta$ or $\leq A_u\cos\beta$

Case 1: Using 1 guy wire and 1 anchor for the three conductors and 1 guy wire and 1 anchor for both OHGW, the following general equations result (1/1 leads).

   For the 3 conductors:

   $3(550) + 3(2.703)(HS)(\cos \theta/2) + 3(52800)(\sin \theta/2) \leq G_u \cos\beta$ or $\leq A_u\cos\beta$
   $1650 + 8.109 (HS)(\cos \theta/2) + (158,400)(\sin \theta/2) \leq 14,700$ lbs.(for guy)
   $1650 + 8.109 (HS)(\cos \theta/2) + (158,400)(\sin \theta/2) \leq 11,300$ lbs. (for anchor)

   For the 2 OHGW's:

   $2(1.840)(HS)(\cos \theta/2) + 2(29,954)(\sin \theta/2) \leq G_u \cos\beta$ or $\leq A_u\cos\beta$
   $3.680(HS)(\cos \theta/2) + (59,908)(\sin \theta/2) \leq 14,700$ lbs. (for guy)
   $3.680(HS)(\cos \theta/2) + (59,908)(\sin \theta/2) \leq 11,300$ lbs. (for anchor)

Case 2: Using 2 guy wires and 2 anchors for the three conductors and 1 guy wire and 1 anchor for both OHGW, the following general equations result (1/1 leads).

   For the 3 conductors:

   $1650 + (8.109)(HS)(\cos \theta/2) + (158,400)(\sin \theta/2) \leq (2)14,700$ lbs. (for guy)

$1650 + (8.109)(HS)(\cos \theta/2) + (158{,}400)(\sin \theta/2) \leq (2)11{,}300$ lbs. (for anchor)

For the OHGW: (same as above)

See the Guying Guide at the end of this example for plots of controlling equations.

e. Checking for buckling of the poles. Since the outside poles carry the maximum axial load, it is necessary only to examine this pole. Longitudinal buckling is considered since this condition is the critical case. Weight of the conductor and OHGW is included in the calculations.

The following example calculations are for Case 1 above.
The maximum axial load which various poles can sustain can be calculated for various heights of structures. The Gere and Carter method is used to calculate P_{cr} below:

Pole Class & Height	Unbraced Length, ℓ Ground to Lowest Guy Attachment, ft.	d_g in.	d_a in.	I_A At Point d_a ($\pi d^4/64$) in^4	$P_{cr} = \frac{\pi^2 E I_A}{\ell^2}\left(\frac{d_g}{d_a}\right)^{2.0}$ pinned-pinned assumed lbs.
60-1	42	15.03	9.83	458	79935
60-2		14.09	9.14	343	60733
60-3		13.15	8.44	249	45108
80-1	60	16.72	9.76	445	47784
80-2		15.64	9.05	329	35948
80-3		14.55	8.35	239	26485

Assuming that horizontal spans are equal to the vertical span, the previous equations in item d above be revised to include the weight of the conductor and OHGW on the outside pole. The total axial load in the pole is the sum of the axial loads induced in the pole from guying the three conductors and two OHGW, and the vertical weight of the OHGW and conductor. Half of the vertical load from the outside phase is carried by the middle pole and other half is carried by the outside pole. For this example, since the guy leads are 1 to 1, the vertical axial load from the guy wire will be equal to the horizontal component of the guy wire.

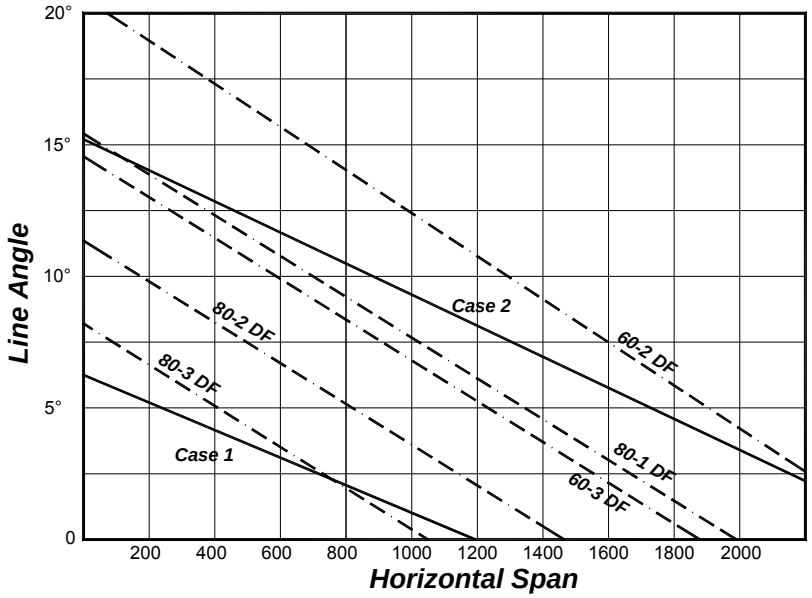
	Wire Weight +	Induced Axial Load, Guying 3 conductors and 2 OHGW's			
Cond.	$1.5(.5)(2.0938)HS+$	$8.109(HS)(\cos \theta/2)$	$+1652$	$+158{,}400(\sin\theta/2)$	
OHGW	$1.5(.9804)HS +$	$3.680(HS)(\cos \theta/2)$		$+ 59{,}908(\sin\theta/2)$	
Total	$(3.0401)HS +$	$11.789(HS)(\cos \theta/2)$	$+1652$	$+218{,}300(\sin\theta/2)$	$\leq .65P_{cr}$

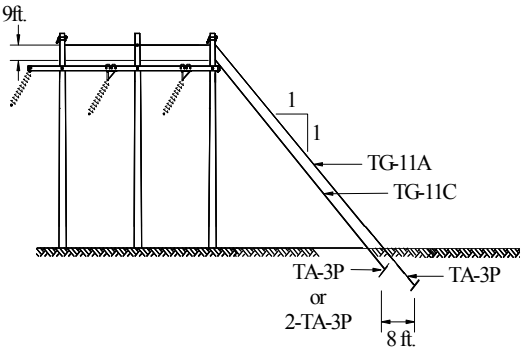
GUYING GUIDE

Structure:	TH – 12	Ruling Span	800 ft.
Conductor Type:	795 26/7	Max. Tension (L, M, H):	10,400 lbs.
OHGW Type:	7/16″ E. H. S.	Max. Tension (L, M, H):	5,900 lbs.
Guy Wire Type	7/16″ E. H. S	Ultimate Strength	20.800 lbs.

Heavy Loading District

p_C:	0.7027 lbs./ft.	p_g:	0.4783 lbs/ft.
w_C:	2.0938 lbs./ft.	w_g:	0.9804 lbs/ft.





Line Angle chart/drawing

Case 1

For OHGW: TG - 11A, TA - 3P
For conductor: TG - 11A, TA - 3P

Total guys and anchors:
(2) TG - 11A
(2) TA - 3P

Limitation: TA-3P to conductor

Case 2

For OHGW: TG – 11A, TA-3P
For conductor: TG – 11C, (2)TA - 3P

Total guys and anchors:
1 - TG – 11A
1 - TG – 11C
3 - TA – 3P

Limitation: TA - 3P to conductor

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15. HARDWARE

15.1 General: Hardware for transmission lines can be separated into conductor-related hardware and structure-related hardware.

Conductor-Related Hardware**:** For many transmission lines, the conductor may constitute the most expensive single component of investment. Yet, this is the one component which is most exposed to danger and most easily damaged. In the design of any line, appropriate emphasis should be given to mechanical and electrical demands on the design of conductor-related hardware used to support, join, separate, and reinforce the overhead conductor and overhead groundwire. Conductor motion hardware is used to diminish damage to the overhead conductors from vibration. Selection and proper installation of conductor accessories will have considerable influence on the operation and maintenance of a transmission line. Electrical, mechanical, and material design considerations are generally involved in the design of conductor support hardware and conductor motion hardware.

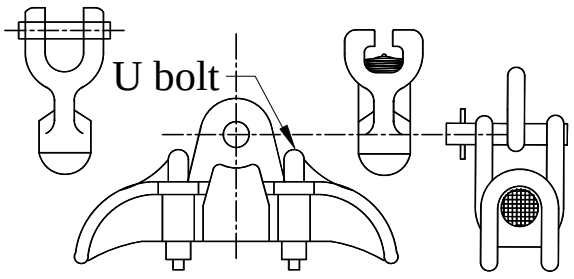
Structure Related Hardware**:** This includes any hardware necessary to frame a structure, to accommodate guying and other types of pole attachments to the structure and to provide necessary conductor-to-structure clearances. As structure–related hardware items are the connecting pieces for structural members, proper selection of this hardware is necessary to assure structure strength. At the same time, proper selection of structure-related hardware includes use of designs that are static proof or incorporate static proof aids to help minimize possible radio and television interference emanations from the line (see Appendix I).

Selection of conductor-related and structure-related hardware should consider corrosion and the damage and degradation of strength and visual esthetics that corrosion can cause. In addition to selecting hardware made of materials that are less likely to corrode, the designer should be certain that the materials selected are compatible with one another and will not corrode when in contact with each other.

15.2 Conductor-Related Hardware

15.2.1 Suspension Clamps: Contoured suspension clamps are designed to match the conductor diameter in order to guard against conductor ovaling and excessively high compressive stresses on the conductor. Suspension clamps may be made from galvanized malleable iron or forged steel. Aluminum liners are recommended for aluminum conductors. Copper liners are recommended for copper conductors only. The connector fitting will usually be either a socket or clevis (see Figure 15-1). When using clamps with liners on conductors covered by armor rods, designers should select clamps that have the proper seating diameter for the effective diameter of the conductor and armor rod. Liners can be expected to add 1/10 inch to the conductor diameter. There are a few clamps made for large line angles (up to 120^{o}). However, these clamps are available only for small conductor sizes. When a transmission line with large conductors has to make a turn along its route, strain clamps should be used. In the case of medium angles (greater than a 30 degree line angle) double suspension clamps connected to a yoke plate may be needed to make a gradual turn.

FIGURE 15-1: SUSPENSION CLAMP WITH CLEVIS OR BALL AND SOCKET TYPE OF CONNECTION



Cushioned suspension clamps are sometimes used to support the conductor and reduce the static and bending stresses in the conductor. Cushioned suspension clamps are further explained in the conductor motion hardware section (Section 15.3).

15.2.2 Clamp Top Clamps: Clamp top clamps for vertical and horizontal post insulators are popular because of they are simple to install. The clamps, made of malleable iron or aluminum alloy, are mounted on a metal cap. The clamp itself is composed of a removable trunion cap screw (keeper piece) and a trunion saddle piece (Figure 15-2).

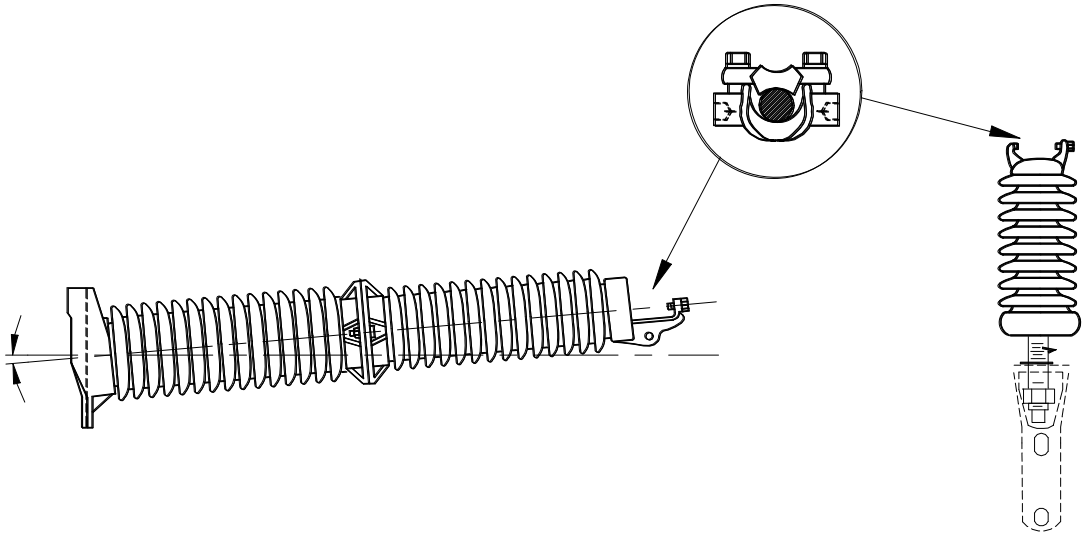


FIGURE 15-2: POST TYPE INSULATOR WITH STRAIGHT LINE TRUNION CLAMPS

Straight line clamps are designed to hold conductors without damage on tangent and line angles of up to approximately 15^{o}. The maximum acceptable vertical angle (each side of clamp) is considered to be approximately 15^{o} with the horizontal. Since the keeper piece of the clamp is not designed to provide the support for upward loading, this clamp should not be used where uplift conditions could occur. Angle clamps are available which are designed to take up to a 60^{o} line angle. However, when line angles are greater than 15^{o} to 20^{o}, suspension insulators should be used. The designer should coordinate with the trunion clamp manufacturer concerning the compatibility of the clamp design for longitudinal loads on the line.

15.2.3 Tied Supports: A large portion of lower voltage construction involves tying conductors to pin and post insulator supports. Hand ties (Figure 15-3) are occasionally vulnerable to loosening from various forces and motion from differential ice buildup, ice dropping, galloping, and vibration. Factory formed ties with secure fit, low stress concentration and uniformity of installation may eliminate mechanical difficulties and radio interference problems associated with loose tie wires.

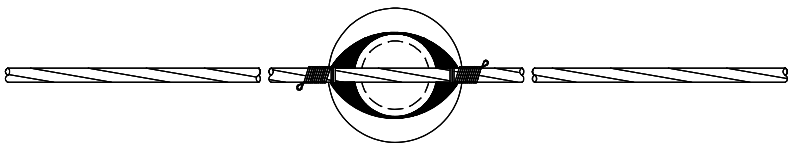


FIGURE 15-3: TOP GROOVE HAND TIE

15.2.4 <u>Deadend Clamps</u>: Deadending a conductor may be accomplished by using formed type deadends, automatic deadends, bolted deadends or compression type deadends (See Figures 15-4a and 15-4b). Because of the strength limitations of formed and automatic deadends, these types are limited to primarily small conductor sizes and distribution line use. The two basic methods of deadending a transmission conductor are by use of bolted deadend clamps and by compression type deadend clamps.

Deadend clamps, or strain clamps as they are sometimes called, are made from three basic types of material as follows:

<u>Aluminum Alloy Type</u>:

General Notes: This type is corrosion resistant. It minimizes power losses, minimizes hysteresis and eddy currents, minimizes excessive conductor heating in the conductor clamping area and is lightweight. This clamp is the most widely used.

Application: No armor rods or tape are required. Clamps are to be used with ACSR or all aluminum conductors. These clamps are not to be used with copper or copperclad conductors.

<u>Malleable Iron</u>:

General Notes: This clamp is somewhat lightweight. The range of conductor sizes is limited.

Application: Clamps are to have aluminum or copper liners. Clamps with copper liners are to be used for copper or copper-clad conductors. Clamps with aluminum liners are used for ACSR and other aluminum composite type conductors

<u>Forged Steel</u>:

General Notes: Forged steel clamps are heavy in weight.

Application: Clamps may be used with all aluminum, copper or ACSR conductors. Clamps are to have aluminum or copper liners. Clamps with copper liners are to be used for copper or copper-clad conductors. Clamps with aluminum liners are used for ACSR and other aluminum composite type conductors.

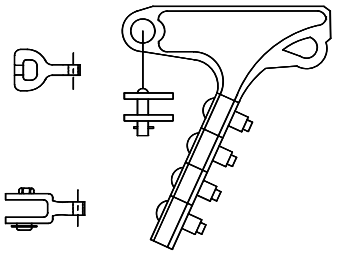


FIGURE 15-4a: TYPICAL BOLTED DEADEND CLAMP

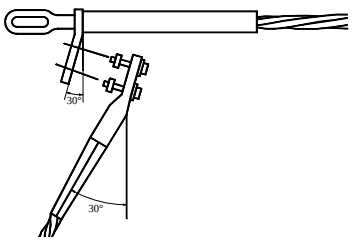


FIGURE 15-4b: TYPICAL COMPRESSION DEADEND

The ultimate strength of the body of the bolted clamps should meet or exceed the ultimate strength of the conductor the clamp is designed to hold. The holding power of a bolt type or compression type clamp should meet the following criteria:

- Clamps have to be capable of holding at least 90 percent of the strength of the largest conductor for which the clamp is designed to hold in a short-time load.
- Clamps have to hold a sustained load of 75 percent of the strength of the conductor for 3 days.

For bolted type clamps, the amount of torque to tighten the bolts depends on the size of the bolt. Torque will range from 300 in-lbs. for 3/8" bolts to 400 in.-lbs. for 5/8" bolts. Clamps should also meet certain corrosion resistance tests and heat cycling tests.

Suspension and deadend clamps for use on high voltage transmission lines are specially designed to control corona. Designs usually involve providing smooth and rounded surfaces rather than sharp edges and by placing all the clamp nuts and studs within the protection of the electrical shield.

Installation of compression splices, deadend clamps, and bolted deadend clamps should follow the manufacturer's recommendations.

15.2.5 Splices: Conductor splices may be automatic compression type splices, formed type splices, or crimp compression type splices. For most transmission conductors, the crimped compression type splice is used because of its high strength capabilities. Splices should meet the same strength, corrosion resistance and heat cycling requirements as the deadend clamps.

15.2.6 Strain Yokes: Two or more insulator strings may be connected in parallel by using yokes to:

- Provide the strength needed to sustain heavy loads at deadend structures;
- Increase the safety factor for long-span river crossings; and
- Make a gradual turn at large angles.

Usually, it is more economical to supply higher strength rated insulators than to use yokes. One disadvantage to using higher strength rated insulators (36,000 lbs and higher) is that the ball and socket size changes for porcelain insulators which will require other related hardware to be coordinated.

15.2.7 Insulators: Mechanical and electrical requirements of insulators are discussed in Chapter 8. Where suspension insulators are exposed to salt sprays or corrosive industrial emissions, insulators using enlarged pin shafts or corrosion intercepting sleeves are recommended to prolong the life of the insulator pins. Use of corroision intercepting sleeves provide an air space between the pin and the cement. With this design, corrosion can attack the expandable long-lived sleeve. Any increase in the volume of the rust line only distorts the sleeve. However, without the sleeve, bursting stresses would be imposed on the adjacent porcelain. Other types of insulators have enlarged shafts near the cement lines which provide additional sacrificial metal for corrosion.

On lower voltage lines, pin and post type insulators are mounted on structure crossarms. The side and top wire grooves generally limit the size of the conductor with armor rods that can be installed to a maximum of 4/0 and 336.4 kcmil ACSR.

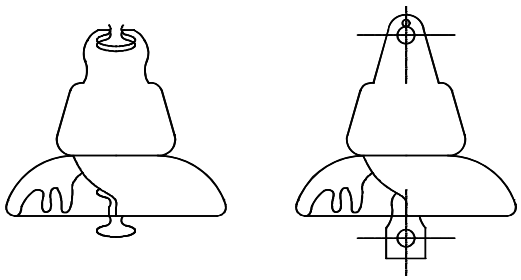


FIGURE 15-5: SUSPENSION INSULATORS
(Ball and Socket Type, Left, and Clevis-Eye Type, Right)

15.2.8 Fittings: Fittings used to attach the insulator to the structure may include hooks, "Y" ball/clevis, ball eyes, ball clevises and chain, anchor or vee shackles. The "C" hooks suggested on agency standard construction drawings are the self locking hooks. With the insulator cap in place, the opening of the hook is sufficiently restricted so that accidental disconnection cannot occur. Fittings should meet or exceed the ANSI M&E ratings of the insulators. Various fitting types are shown in Figure 15-6, 15-7 and 15-8.

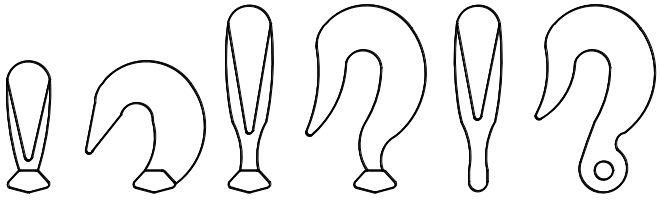


FIGURE 15-6: DIFFERENT TYPES OF HOOKS
(Self Locking "C" Hook, Left; Ball Hook, Middle, Clevis Type Hook, Right)

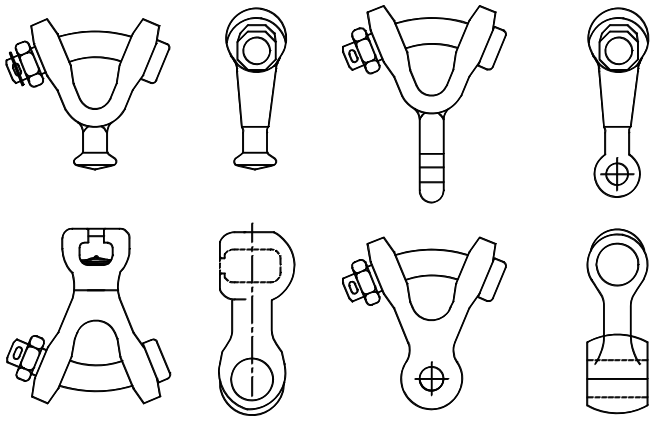


FIGURE 15-7: VARIOUS TYPES OF BALL AND CLEVIS "Y" CONNECTIONS

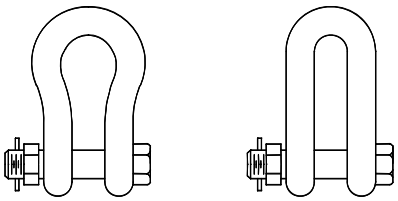


FIGURE 15-8: ANCHOR SHACKLE (Left); CHAIN SHAKLE (Right)

15.3 Conductor Motion Hardware

15.3.1 Aeolian Vibration: All conductors are in some state of vibration, varying from extremely slight to temporarily severe. Selection of the proper hardware to improve conductor life will depend on the degree of vibration. Suspension clamps do not restrict vibration, but these clamps should be designed to keep to a minimum the effect of such vibration on the conductor. Methods to reduce the effects that aeolian vibration has on lines include the following:

Armor Rods**:** Armor rods (Figure 15-9) should be used on lines in areas where mild vibrations may occur. Armor rods, wrenched or preformed, are helical layers of round rods which are installed over the conductor at the points of attachment to the supporting structures. The primary purpose of armor rods is to provide additional rigidity to the conductor at its point of support. The use of armor rods accomplishes:

- Alleviating changes of mechanical stress buildup at the point of support by providing a gentler slope of curvature for the incoming conductor,
- Increasing conductor life from fatigue failure by increasing the flexural rigidity of the conductor, and reducing bending stresses in the conductor,
- Protecting the conductor from flashover damage and mechanical wear at the points of support.

In laboratory tests, the placement of armor rods on the conductor has allowed the conductor to withstand considerably more vibration cycles without fatigue failure. Tests such as these show that there is a significant reduction in stress afforded through the use of armor rods.

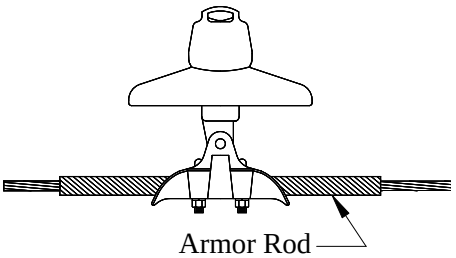


FIGURE 15-9: ARMOR RODS USED WITH SUSPENSION INSULATORS

Cushioned Suspension Units**:** These units use resilient cushioning in conjunction with armor rods to further reduce the static and dynamic bending stresses in the conductor (See Figures 15-10a and 15-10b). With this cushioning, the compressive clamping force is decreased, thereby reducing stress concentration notches. For line angles greater than 30^{o}, single support units should be replaced with double units. When considering longitudinal loads for a line using cushioned suspension units, the designer should consider that the units have a slip load of approximately 20 percent of the rated breaking strength of the conductor. A disadvantage to cushioned suspension units is that it is very difficult to remove or install these units with hot line tools.

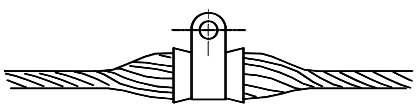


FIGURE 15-10a:
CUSHIONED SUSPENSION UNIT

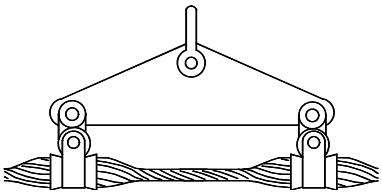


FIGURE 15-10b:
DOUBLE CUSHIONED SUSPENSION
(For Line Angles Greater Than 30º)

Dampers**:** These are used in areas of severe vibration. They act to attenuate aeolian vibration amplitudes and thereby reduce the dynamic bending stress at hardware locations and extend conductor life. Suspension dampers (figure 15-11) make use of the connecting cables between weights to dissipate the energy supplied to the damper. Use of spiral dampers (Figure 15-12) is limited to small conductor sizes (Figure 15-12).

When a vibration wave passes the damper location, the clamp of a suspension type damper oscillates up and down, causing flexure of the damper cable and creating relative motion between the damper clamp and damper weights. Stored energy from the vibration wave is dissipated to the damper in the form of heat. For a damper to be effective, its response characteristics should be consistent with the frequencies of the conductor on which it is installed. Dampers of various designs are available from a number of manufactures. The number of dampers required, as well as their location in the span should be determined by consultation with the damper manufacturer.

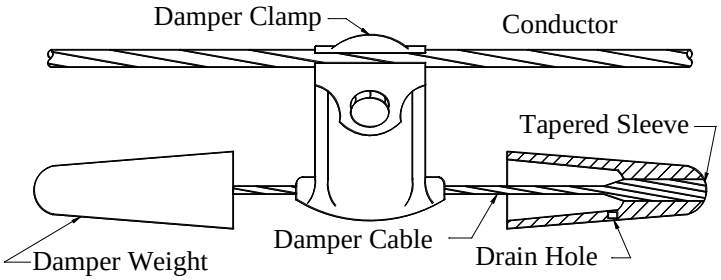


FIGURE 15-11: TYPICAL SUSPENSION DAMPER

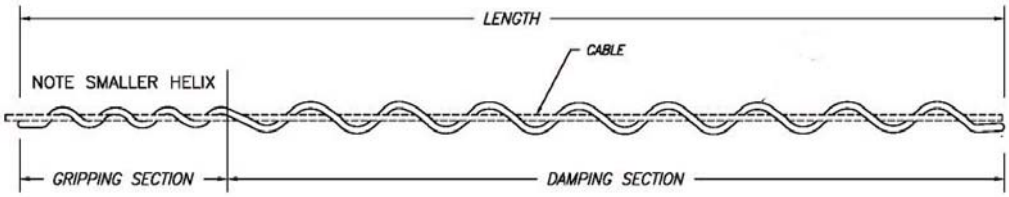


FIGURE 15-12: SPIRAL VIBRATION DAMPER FOR SMALL CONDUCTORS

Application of armor rods, cushion suspension or dampers or a combination thereof should be on a case-by-case basis. A certain item should not be used merely because it has given satisfactory performance in another location.

If prevailing wind conditions and the terrain are such that vibration will occur most of the time, some form of vibration protection should be investigated. Dampers should be selected on the basis of the frequencies one expects to encounter in the terrain that must be traversed. The engineer should not specify a certain type of damper or armor rod simply because everyone else is using them. An improperly located damper can affect the amount of protection and ability of the damper to suppress the damaging effects of aeolian vibration.

Armor rods are meant to be reinforcement items, not dampers. Vibrations are passed on through the conductor clamp basically without any attenuation, and then dissipated in the supporting structure. If the structure is made of steel and if fatigue can be a problem then use of dampers along with armor rods should be investigated. However, care should be exercised in selecting the distance between the ends of the armor rods and the dampers, if both are to be used.

15.3.2 Galloping: Hazards associated with galloping conductors include:

- Contact between phases or between phase conductors and ground wires,
- Racking of the structure,
- Possible mechanical damage at supports.

Aerodynamic drag dampers and interphase spacers are used to limit the amplitude of the conductor during galloping. Historically, effectiveness of anti-galloping devices has been erratic.

15.3.3 Bundled Conductors: Bundled connectors are not used very often on transmission lines under 230 kV but are often economically justified above 230 kV. Bundled conductors can experience aeolian vibration, galloping, corona vibration, and subconductor oscillation. For a bundled conductor with spacers, aeolian vibration may be reduced by a factor of 10. However, galloping of ice coated conductors will occur more readily and more severely on bundled lines than on single conductors in the same environment.

Subconductor oscillation, though, has caused a major share of the problems to date. It is caused by one conductor lying in the wake of an upstream conductor and thereby being excited to vibrate in a nearly horizontal ellipse. Damage has consisted of conductor wear as well as spacer deterioration and breakage. To reduce subconductor oscillation, subspan length or the distance between spacers should be kept below 250 feet.

The primary purpose of spacers is to reduce the probability of conductor contact and magnitude of vibration. Spacers may be rigid, articulated or flexible. They may be open-coil and closed-coil springs, and wire rope and steel strand connecting members. Spacers should grip bundled conductors securely to avoid abrasion of the subconductors and to prevent conductor entanglement during strong winds.

15.3.4 Insulator Swing: Occasionally, tie-down weights are used to control conductor position by preventing excessive uplift and swinging. A line should not be designed to use tie-down weights as a means of preventing the conductor from swinging into the structure. Sometimes due to a low Vertical/Horizontal span ratio, weights may have to be used on an occasional structure. Two types of tie down weights are shown in Figure 15-13.

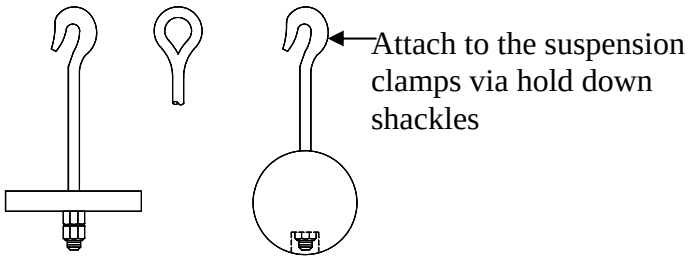


FIGURE 15-13: DISC WEIGHTS (Left), BALL WEIGHTS (Right)

15.4 Structure Related Hardware for Wood Structures

15.4.1 Fasteners: Threaded rods and machine bolts are frequently used on wood transmission structures (Figure 15-14). A static-proof bolt has a washer securely fixed to the head of the bolt and is furnished with washer nuts. Variations of the static-proof bolt include shoulder eye bolts with round or curved washers welded to the eye, forged shoulder eye bolts and forged eye bolts. MF type locknuts, used in conjunction with a regular nut or washer nut, form a solid unit which

does not loosen from vibration and helps to maintain a static proof installation. The strengths and tensile stress areas of bolts conforming to ANSI C135.1 are shown in the Table 15-1.

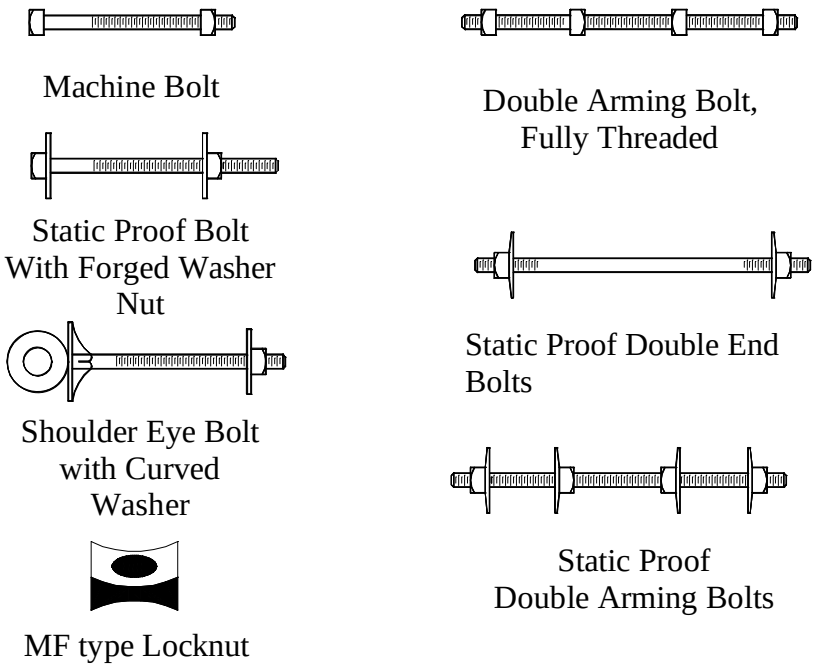

Machine Bolt
Double Arming Bolt, Fully Threaded
Static Proof Bolt With Forged Washer Nut
Static Proof Double End Bolts
Shoulder Eye Bolt with Curved Washer
Static Proof Double Arming Bolts
MF type Locknut

FIGURE 15-14: FASTENERS

TABLE 15-1
STRENGTHS OF ANSI C135.1 MACHINE BOLTS, DOUBLE ARMING BOLTS, AND DOUBLE END BOLTS

Machine Bolt Diameter in.	Tensile Stress Area sq. in.	Minimum Tensile Strength lbs.
1/2	0.142	7,800
5/8	0.226	12,400
3/4	0.334	18,350
7/8	0.462	25,400
1	0.606	33,500

Lag screws (Figure 13-5) are sometimes used in lieu of bolts when shear loads are small. A lag screw with fettered edges is driven into the wood and maintains its holding power with cone shaped threads. When lag screws are used, the moment capacity of the wood pole is reduced in the same manner as a bolt hole reduces moment capacity.

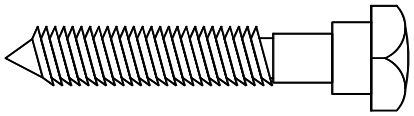
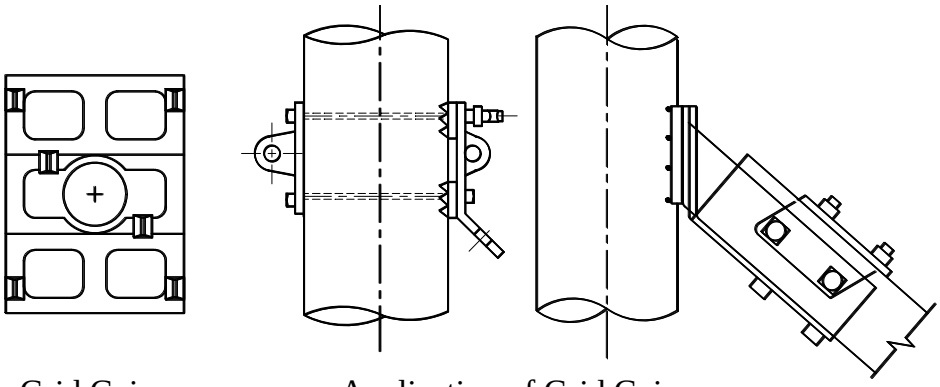


FIGURE 15-15: LAG SCREW

Anti-split bolts help prevent the propagation of checking and splitting at the end of crossarms. A three inch edge distance should be provided between the anti-split bolt and the edge of the arm.

15.4.2 Framing Fittings: The primary purpose for using grid gains is to reduce bolt hole slotting by distributing the shear load of the bolt over a large wood area. The specially shaped teeth of the grid gain press into the wood surface and offer maximum resistance to movement both with and across the grain of the wood. The use of grid gains will strengthen bolt connections and are recommended anytime a bolt must carry large shear loads. Two applications of grid gains are shown in Figure 15-16.

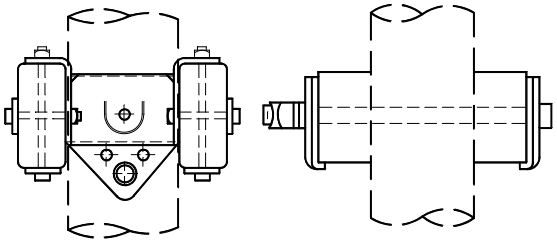


Grid Gains Application of Grid Gains

FIGURE 15-16: GRID GAINS

The gain plate (between a pole and a crossarm) and the reinforcing plate (on the outside of an arm) provide additional metal bearing surface for transfer of the vertical load from the crossarm to the crossarm mounting bolt. The gain plate eliminates a potential decay area between two wood contact areas. A reinforcing plate, also called a ribbed tie plate, will prevent the crossarm from splitting or checking when the nut is tightened.

When double crossarms are used to allow longer vertical spans or to increase longitudinal strength capabilities, spacer fittings Figure 15-17 are needed to separate the crossarms and to provide a point of attachment for suspension insulators. If fixed spacers are used, poles should be gained. Since the standard fixed spacing sizes are 7-1/2", 9", 10-1/2", and 12", the crossarm may be bowed ±1/2 inch. The brand on the butt and face of the pole should include proper designation of the fixed spacer size. Adjustable spacers will fit a range of pole diameters. When they are used the pole need not be gained.



Spacer Fitting Reinforcing Plate and Gain Plate

FIGURE 15-17: SPACER FITTING, REINFORCING PLATE AND GAIN PLATE

15.4.3 Swing Angle Brackets: Swing angle brackets are used to provide increased clearance between phase conductors and the structure to which the conductors are attached (Figure 15-18). These brackets cab be mounted horizontally or vertically. The two primary types of angle brackets are the rod type for light loads, and angle iron type for heavier loads.

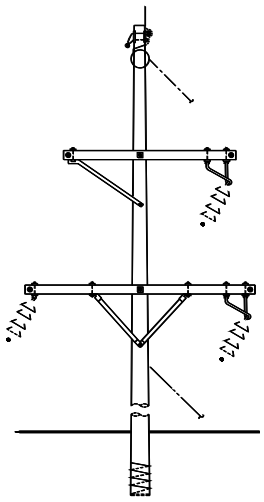


FIGURE 15-18: SMALL ANGLE STRUCTURE WITH SWING ANGLE BRACKETS

15.4.4 Guy Attachments: The primary types of guy attachments used on wood transmission line structures include the wrap guy, guying plates, pole eye plates, guying tees, and pole bands. Other types of guy attachments such as formed straps, angle bolt eyes, and goat hooks are used primarily on distribution lines. Guy attachments are used to attach the insulators to the structure as well as providing a means of guying the structure.

15.5 Structure Related Hardware for Concrete and Steel Structures: Much of the structure related hardware used on wood construction may be appropriate to use on steel or concrete structures. However, hardware items with grid teeth, such as grid gains or guy attachments with grid teeth, are not appropriate for use on steel or concrete structures. Likewise, lag screws and gain plates are not used on steel and concrete poles. Since steel and concrete poles do not shrink and swell with age and weather, spring washers may not be needed to keep the hardware tight over time.

In many instances, higher strength bolts are used with steel or concrete poles. Bolts such ASTM A325, Specification for High-Strength Bolts for Structural Steel Joints, may be specified instead of the ANSI C135 bolts. Table 15-2 gives the strength ratings for bolts conforming to ASTM Standard A325.

TABLE 15-2
STRENGTHS OF ASTM A325
HEAT TREATED, HIGH STRENGTH BOLTS

Machine Bolt Diameter in.	Tensile Stress Area sq. in.	Minimum Tensile Strength lbs.	Minimum Yield Strength lbs.
1/2	0.142	17,500	13,050
5/8	0.226	27,100	20,800
3/4	0.334	40,100	30,700
7/8	0.462	55,450	42,500
1	0.606	72,700	55,570

Proper selection and design of end fittings and guy attachments is necessary to obtain the necessary capacity. For example, for steel structures, it may be necessary to use reinforcing washers on the backside of a guy attachment or end fitting to prevent the nut or bolt head from pulling through the wall of the steel pole. Selection of hardware should be coordinated with the

steel pole supplier or concrete pole supplier to obtain the capacity and performance desired. Selection of hardware should also consider proper fit with other hardware.

When using standard class concrete or steel poles, the owner should provide the pole manufacturer with the load capabilities, attachment method, and attachment location of all appurtenances. The pole manufacture should verify that the pole will not have a localized strength problem at the attachment point. Items to consider if standard class steel or concrete poles are guyed include:

- Localized buckling at the guy attachment,
- Field holes in the wrong locations,
- Unexpected torsion on the pole due to the fact that the pole is not round and the correct guy plate location does not fall on one of the pole's flat surfaces, and
- Sliding of the slip joint under heavy conductor loads.

In the use of concrete and steel structures, a means for climbing the structure should be provided. The NESC Rule 261N states the requirements for climbing devices and attachments to the structure. Based on this requirement, it is recommended that step bolts, removable steps, ladders, and each attachment to the pole be designed to support a minimum of a 300-pound worker and equipment multiplied by a 2.0 load factor. The load should be applied at the outer edge of the step or bolt and should be supported without permanent deformation. Refer to agency Bulletins 1724E-204, -206, -214, and -216, for additional guidelines on the use of concrete and steel structures.

15.6 <u>Corrosion of Hardware</u>: Corrosion may be defined as the destruction of metal by a chemical or electro-chemical reaction with its environment. Certain industrial and sea coast environments accelerate the rate of corrosion. Parameters which stimulate corrosion include air (oxygen) dissolved in water, airborne acids, sulphur compounds (from cinders, coke, coal dust,) salt dissolved in water, corona, etc.

Any two dissimilar metals when placed together in the presence of an electrolyte form a simple battery. One metal becomes an anode, sacrificing itself to the other metal which becomes the cathode. One method to reduce the rate of corrosion is to select metals which are compatible with one another. Table 15-3 details the galvanic voltage of various metals commonly used for transmission line hardware. The greater the algebraic difference between the metals selected, the more rapid the rate of corrosion will be of the more electronegative metal selected.

TABLE 15-3
GALVANIC TABLE OF VARIOUS METALS

Silver	+.79
Copper	+.34
Lead	-.13
Tin	-.15
Iron	-.35
Chromium	-.47
Zinc	-.77
Aluminum	-1.337

As an example, when malleable iron suspension clamps are used, aluminum liners should be furnished in order to reduce the rate of corrosion of the aluminum conductor. As another example, the selection of staples to be used on the pole ground wire must be compatible material to the ground wire (see Drawing TM-9 in Bulletins 1728F-810 and 1728F-811).

Other methods of reducing the rate of corrosion are to galvanize tin plate, paint or cover metals with corrosion inhibitors. The life of used metals can be prolonged by increasing metal thickness.

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16. UNDERBUILD

16.1 General: Placing of underbuild distribution or communications circuits on transmission lines is a practice that is becoming more prevalent as available rights-of-way decrease. Although underbuild distribution lines increase the initial cost of a transmission line, common sharing of a right-of-way is sometimes necessary in order to build the line.

The following factors should be considered in designing a common use line: hazards to personnel and property, costs, difficulties of construction, operation and maintenance. Adequate structure arrangement and conductor separation should be provided to minimize the possibility of conductor contacts, and to provide safe working conditions. Adequate electrical protection involves prompt and positive de-energization of power circuits in the event of conductor contact or flashover. Obtaining and maintaining a low ground resistance to earth is desirable to limit the magnitude of voltage rise, duration of hazardous voltage, and lightning damage.

16.2 Addition of Distribution Underbuild to an Existing Transmission Line: Distribution circuits can be added to existing transmission structures only if the original transmission structure was designed for the new particular underbuild facilities or the total structure facilities meets the current edition of the NESC.

16.3 Strength Requirements: Standard distribution construction is required to meet NESC Grade C construction in accordance with 7 CFR Part 1724. However, underbuild distribution on transmission circuits, with the exception of the crossarms, are to be built to meet all requirements of NESC Grade B construction. This means that the loading on the pole due to the distribution circuits has to be calculated using NESC Grade B overload capacity factor and strength factors, It also means that all guying for the underbuild must meet the guying requirements for transmission. Distribution crossarms on transmission structures may be designed for NESC Grade C construction, except at angles where they have to be designed for NESC Grade B construction.

16.4 Line-to-Ground Clearances: Since the lowest conductors on a transmission line with underbuild will usually be those of the distribution circuits, the clearances to ground and clearances in crossing situations will in most instances be limited by the requirements stipulated in the NESC for distribution circuits.

The problem of providing satisfactory clearance becomes more involved when multiple distribution circuits or conductors cross on the same structure. In these instances, very careful attention need to be given to the allowable clearance in Section 23 of the NESC.

Particular attention should be given to the use of reduced size distribution neutrals since the clearance to ground for the neutral, by virtue of its increased sag and position on the pole or crossarm, may be the controlling factor for pole height. In some cases, it may be more economical to increase the size of the neutral to reduce its sag.

16.5 Separation Between Transmission and Underbuild Distribution Circuits: The clearances discussed in this section are intended to provide not only operating clearances but also sufficient working clearances. A distribution line worker has to be able to access and work on the distribution underbuild without encroaching upon the required safety (zone) clearances of the transmission conductors.

16.5.1 Horizontal Separation: The horizontal separation at the support between the lowest transmission conductor(s) and the highest distribution conductor(s) or neutral should be at least 1 foot if possible as illustrated in Figure 16-1.

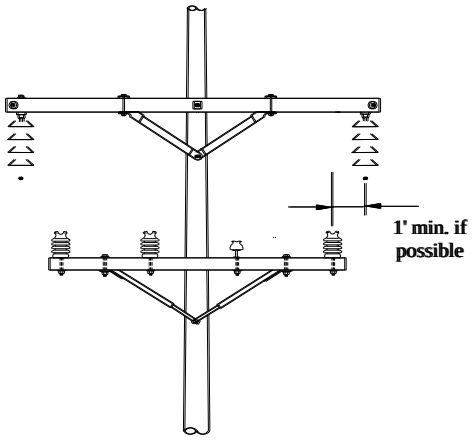

FIGURE 16-1: HORIZONTAL SEPARATION REQUIREMENTS BETWEEN TRANSMISSION AND UNDERBUILD

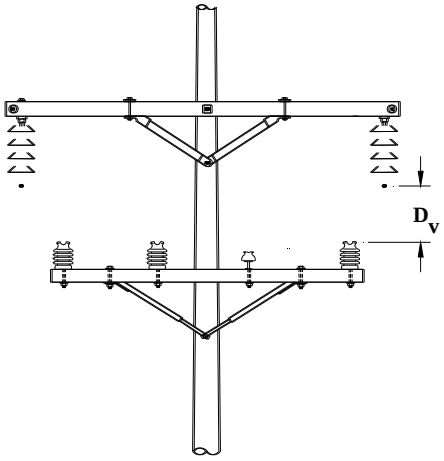

FIGURE 16-2: VERTICAL SEPARATION REQUIREMENTS AT STRUCTURE FOR UNDERBUILD

16.5.2 Vertical Clearance to Underbuild at Supports: Recommended minimum vertical clearances between the transmission conductors and the underbuild conductors at the support are shown in Table 16-1. These clearances apply regardless of the amount of horizontal separation between transmission and underbuild conductors (see Figure 16-2).

16.5.3 Vertical Clearance to Underbuild at any Point in the Span: Recommended minimum vertical clearances at any point along the span are shown in Table 16.1.

These clearances apply for the condition below which yields the least separation between the upper and lower conductor.

a. An upper conductor final sag at a temperature of 32°, no wind, with radial thickness of ice for the applicable loading district;
b. An upper conductor final sag at a temperature of 167ºF;
c. Upper conductor final sag at a maximum design temperature, no wind. For high voltage bulk transmission lines of major importance to the system, consideration should be given to the use of 212ºF as the maximum design conductor temperature.

The sag of the underbuild conductor to be used is the final sag, at the same ambient temperature as the upper conductor without electrical loading and without ice loading.

If the transmission line or portion thereof is at an altitude which is greater than 3300 feet, an additional clearance (as indicated in Table 16-1) has to be added to both clearances at the structure (Category 1) and clearances at the midspan point (Category 2).

16.5.4 Additional Clearance Requirements for Communication Underbuild: For communication underbuild, the low point of the transmission conductors at final sag, 60˚ F, no wind, should not be lower than a straight line joining the points of support of the highest communication underbuild.

TABLE 16-1
RECOMMENDED MINIMUM VERTICAL CLEARANCES TO DISTRIBUTION OR COMMUNICATION UNDERBUILD ON TRANSMISSION LINES IN FEET
(Circuits may be of the same or different utilities)
(Based on NESC Rule 235 and Table 235-5)

Transmission Nominal voltage, Phase to Phase kV_{L-L}	**34.5**	**46**	**69**	**115**	**138**	**161**	**230**
Max. Operating Voltage, Phase to Phase kV_{L-L}	36.2	48.3	72.5	120.8	144.9	169.1	241.5
Max. Operating Voltage, Phase to Ground kV_{L-G}	20.2	27.9	41.8	69.7	83.7	97.6	139.4
Vertical Clearances Between Transmission and Distribution Conductors	**Clearances in Feet**						
1. Clearance at the support from point of suspension of transmission conductor to point of suspension of underbuild distribution or communication conductor. Nominal underbuild voltage in kV line-to-line: (Note A)							
a. 25 kV and below (including communications conductors)	4.7	5	5.4	6.4	6.8	7.3	8.7
b. 34.5 kV	4.9	5.2	5.6	6.5	7.0	7.5	8.9
2. Clearance at any point in span from transmission conductor to underbuild conductor. Nominal underbuild voltage in kV line-to-line (Note A):							
a. 25 kV and below (including communications conductors)	3.7	3.8	4.2	5.2	5.6	6.1	7.5
b. 34.5 kV	3.8	4.0	4.3	5.4	5.8	6.3	7.7
Vertical Clearances Between Transmission Conductors and Distribution Structures	**(See Table 4-2)**						
ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE							
Additional feet of clearance per 1000 feet of altitude above 3300 feet	0.02	0.02	0.05	0.06	0.08	0.12	

Note:
(A) An additional .5 feet of clearance is added to the NESC clearance to obtain the recommended design clearances.

16.5.5 Span Length and Clearance to Underbuild: The conditions of either Paragraph 16.5.2 or Paragraph 16.5.3 above will dictate what the minimum clearance to underbuild at the structure should be. If the clearance to an underbuild is dictated by Paragraph 16.5.3 of this section, the clearance at the structure would have to be increased. Vertical separation at the structure may depend upon the relative sags of transmission and underbuild conductors. Since the span length has an effect on relative sags, the resulting maximum span as limited by vertical clearance to underbuild should be calculated to ensure that the vertical separation at the support is correct for each span.

The formula for maximum span as limited by clearance to underbuild is:

$$L_{max} = (RS)\sqrt{\frac{A-B}{S_\ell - S_u}} \qquad \text{Eq. 16-1}$$

where:

L_{max} = maximum span in feet
RS = ruling span in feet
A = allowable separation at midspan in feet
B = vertical separation at supports in feet
S_ℓ = underbuild sag at the same ambient temperature as the transmission conductor, final, in feet
S_u = transmission conductor sag at condition resulting in least separation to underbuild, final sag, in feet

16.6 <u>Climbing Space</u>: Climbing space through the lower circuits should be preserved on one side of the pole or in one quadrant from the ground to the top of the pole as required by the NESC. Working space should be provided in the vicinity of crossarms. Jumpers should be kept short enough to prevent their being displaced into the climbing space.

16.7 <u>Overhead Ground Wires and Distribution Neutrals</u>: Standard distribution underbuild construction has its own neutral. This neutral may be tied to the transmission pole ground wire in order to improve its grounding. Depending on the characteristic of the circuits, a common ground or a separate ground is acceptable. If separate grounds are used, the pole ground wires should be located on opposite sides of the pole. Similar materials should be used for both the transmission pole ground wire and for the distribution pole ground wire and ground rod. For example, if copper is used for the transmission pole ground, then copper and/or copperclad should be used for the distribution ground rod and pole ground wire. Use of similar materials will reduce the possibility of galvanic corrosion. Likewise, the distribution anchors and transmission anchors should be of similar material as the ground rods and wire used for the pole butt wraps.

For distribution underbuild on concrete transmission poles, the neutral may be tied to the external pole ground using a compression connector in locations where the neutral is to be grounded. A lead from the pole ground should then be tied to a separate ground rod via a compression connector six inches to one foot above the ground level. Similarly, in the case of steel poles, there may be situations where the neutral of the distribution underbuild is to be grounded. In these instances, the pole may be used as the ground path but not as a ground electrode. A grounding connector mounted on the pole needs to be specified just below the location of the neutral on the pole. The ground pad near the ground line should then be used to connect a driven ground rod to the pole.

16.8 <u>Addition of Poles for Underbuild</u>: There may be structures where it is either desirable or necessary to transfer distribution circuits to separate poles. Such situations include:

- Large Line Angles (Figure 16-3)
- Deadends
- Tap-offs
- Sectionalizing Structures
- Substation Approaches
- Transformers or Regulators (Figure 16-4)
- Capacitors

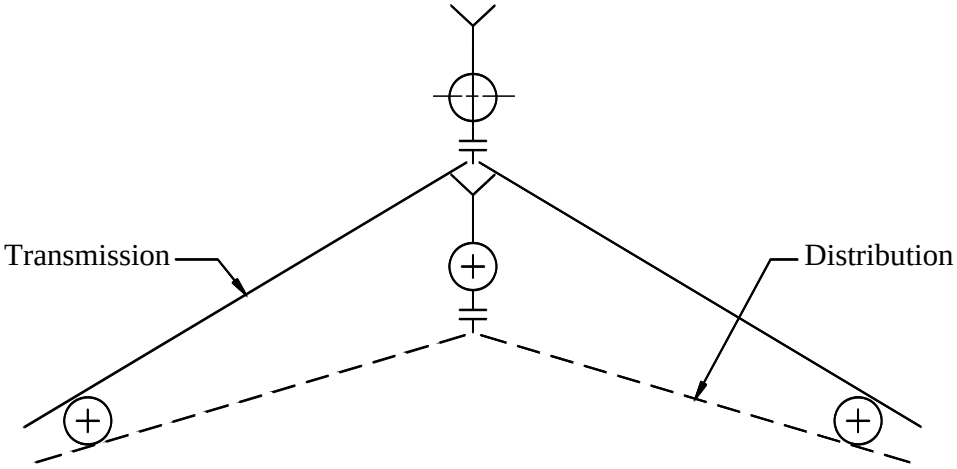

FIGURE 16-3: TRANSFERENCE OF THE DISTRIBUTION CIRCUIT TO A SEPARATE POLE AT A LARGE ANGLE

Location of transformers on structures carrying both transmission and distribution lines should be avoided. Not only does the transformer create an unbalanced load on the structure, but the additional conductors necessary for service drops may make working on the structure hazardous to personnel. A ground rod should be installed at every pole location with a transformer and the transformer grounded per NESC requirements.

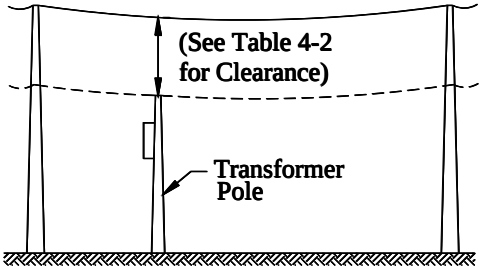

FIGURE 16-4: USE OF A SEPARATE POLE TO MOUNT A DISTRIBUTION TRANSFORMER

16.9 <u>Guying</u>: The need to provide additional guys to compensate for the effect of underbuild on structures is readily apparent. However, there are locations where special attention has to be given to the guying being proposed. One example is a common use pole with a line tap.

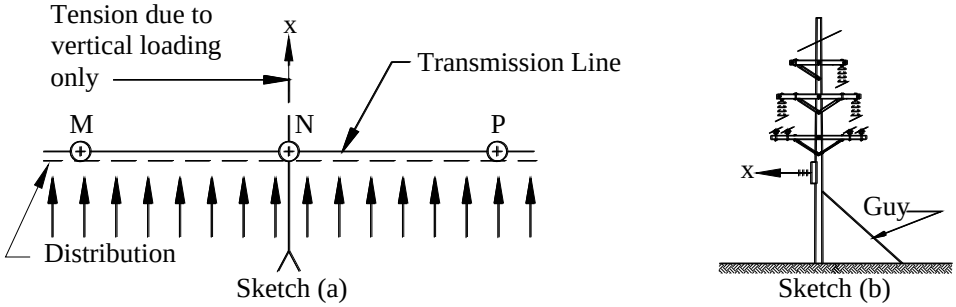

FIGURE 16-5: GUYING DISTRIBUTION UNDERBUILD

For winds perpendicular to the transmission line, the guying described in Figure 16-5 may be insufficient. This will be true if consideration has been given only to underbuild deadend tension shown as forces (x) in the figure. The maximum transverse load acts on half the sum of adjacent spans, (MN+NP)/2, of the transmission and distribution circuits.

These forces have to be added to the tensions of tap conductors in order to determine the proper amount of guying required. If winds are parallel to the transmission line, the deadend loading of the tap is larger and this load should be used. Guying of the distribution underbuild is to meet Grade B construction.

A general rule is that where the transmission circuit or the distribution circuit requires guys, both circuits should be guyed. The guys should be designed to carry the entire transverse load on the structure at maximum loading conditions. All drawings should show location and slope of guys to assure adequate clearances when guys are required. Positions of guys should be clear from other hardware or electrical connections, such as connectors between neutral and pole ground wire. Where guys may pass close to conductors, minimum clearances in accordance with Table 4-2 should be met.

16.10 Example: Maximum Span as Limited by Clearance to Underbuild: A 69 kV single pole transmission is to be built with a 25 kV underbuild distribution circuit. Determine maximum span as limited by clearance between transmission conductors and underbuild.

16.10.1 Given:

- Vertical separation between transmission and distribution conductors at the structure is 11.0 ft.
- Ruling span: 300 ft.
- NESC Heavy loading district
- Conditions for the conductor:
    a. Transmission conductor is at 32°F with ½" ice while the distribution conductor is at an ambient temperature of 0°F during the winter.
    b. Transmission conductor is at 212°F maximum design temperature while the distribution conductor is at an ambient temperature of 0°F during the winter.
    c. Transmission conductor is at 212°F maximum design temperature while the distribution conductor is at an ambient temperature of 90°F during the summer.

	Transmission Conductor 477 kcmil 26/7 ACSR		Distribution Conductor 4/0 6/1 ACSR	
	Loading Condition	Final sag (ft.)	Ambient Temp.	Final sag (ft.)
(a)	32ºF, 1/2" ice	4.40	0°F	1.60
(b)	212ºF	6.73	0°F	1.60
(c)	212ºF	6.73	90°F	3.98

16.10.2 Solution:

From Table 16-1 the required vertical clearance at midspan between the transmission and distribution conductors is 4.2 feet.

Next, calculate the separation between the upper and lower conductor for each loading condition given above:

(a) 11’ - 4.40’ + 1.60’ = 8.20’
(b) 11’ - 6.73’ + 1.60’ = 5.87’
(c) 11’ - 6.73’ + 3.98’ = 8.25’

The condition (b) results in the least separation between the transmission and underbuild conductors; therefore, the condition (b) conductor sag values will be used in the following equation:

$$L_{max} = (RS)\sqrt{\frac{A-B}{S_\ell - S_u}} \qquad \text{Eq. 16-1}$$

Substituting:

RS = 300
A = 4.2
B = 11
S_ℓ = 1.60
= 6.73

$$L_{max} = (300)\sqrt{\frac{4.2-11}{1.60-6.73}}$$

L_{max} = 345 feet

The maximum span as limited by the separation between the transmission conductors and the distribution underbuild is 345 feet.

For situations where greater span lengths are necessary, the separation at the structure should be increased. In addition, consideration should be given for the effects of ice jumping as described in Section 6.3 of this manual.

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APPENDIX A

TRANSMISSION LINE DESIGN DATA
SUMMARY SHEET AND SUPPORTING INFORMATION

- Sample Summary Sheet A-3
- Instructions A-5
- Suggested Outline for Design Data Summary Book A-10

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TRANSMISSION LINE DESIGN DATA SUMMARY

I. GENERAL INFORMATION

BORROWER:	DATE:
LINE IDENTIFICATION:	

VOLTAGE		LENGTH	
TRANSMISSION	UNDERBUILD	TRANSMISSION	UNDERBUILD
_____kV	_____kV	_____mi	_____mi.

TYPE OF TANGENT STRUCTURE:	BASE POLE: _____HT. _____CL
DESIGNED BY:	

II. CONDUCTOR DATA

	TRANSMISSION	OHGW	UNDERBUILD	COMMON NEUTRAL
SIZE *(kcmil or in.)*				
STRANDING				
MATERIAL				
DIAMETER *(in)*				
WEIGHT *(lbs./ft.)*				
RATED STRENGTH *(lbs.)*				

III. DESIGN LOADS (Wires)

		TRANSMISSION *(lbs./ft.)*	OHGW *(lbs./ft.)*	UNDERBUILD *(lbs./ft.)*	COMM.NEUTRAL *(lbs./ft.)*
NESC:_____LOADING DISTRICT					
a. ICE: _____in.	Vertical.				
b. WIND ON ICED COND. ___psf	Transverse				
c. CONSTANT K _____	Resultant + K				
HEAVY ICE*(NO WIND)* _____in.	Vertical.				
HIGH WIND*(NO ICE)* _____psf	Transverse				
EXTREME HIGH WIND/ICE					
ICE: _____in.	Vertical.				
WIND ON ICED COND. ___psf	Transverse				

IV. SAG & TENSION DATA

SPANS AVERAGE*(EST)* _____ft MAXIMUM*(EST)* _____ft.. RULING*(EST)* _____ft.

SOURCE OF SAG-TENSION DATA:	TRANSMISSION		OHGW		UNDERBUILD		COMM.NEUTRAL	
TENSIONS *(% RATED STRENGTH)*	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL
NESC a. UNLOADED (0˚ 15˚ 30˚) _____˚F								
NESC b. LOADED (0˚ 15˚ 30˚) _____˚F								
MAXIMUM ICE 32 ˚F								
HIGH WIND (NO ICE) _____˚F								
UNLOADED LOW TEMPERATURE _____˚F								
SAGS *(FT)*								
NESC DISTRICT LOADED _____˚F								
UNLOADED HIGH TEMP(120˚FOR OHGW &U.B.)___˚F								
MAXIMUM ICE 32˚F								
LOADED 1/2" ICE, NO WIND 32˚F								

V. CLEARANCES

MINIMUM CLEARANCES TO BE MAINTAINED AT:_____

CLEARANCES IN FEET	RAILROADS	HIGHWAY	CULTIVATED FIELDS			ADDITIONAL . ALLOWANCE
TRANSMISSION						
UNDERBUILD						

VI. RIGHT OF WAY

WIDTH _____ FT. *(MIN.)* _____ FT. *(MAX.)*

VII. CONDUCTOR MOTION DATA

HISTORY OF CONDUCTOR GALLOPING:

HISTORY OF AEOLIAN VIBRATION:

a. TYPE OF VIBRATION DAMPERS USED *(IF ANY)*

b. TYPE OF ARMOR RODS USED *(IF ANY)*

VIII. INSULATION

NO. OF THUNDERSTORM DAYS/YR_____ELEV.ABOVE SEA LEVEL (MIN, MAX, ft.)_____

CONTAMINATION EXPECTED?_____MAX EST. FOOTING RESISTANCE_____Ω SHIELD ANGLE _____°

STRUCTURE TYPE	STRUCTURE DESIGNATION	NO. OF BELLS / POLYMER / PIN OR POST	60 HZ DRY FLASHOVER	INSULATOR SIZE (DIAMETER & LENGTH)	SML / M & E RATING / POST STRENGTH	OTHER
TANGENT						
ANGLE						
STRAIN STRUC						

IX. INSULATOR SWING

CRITERIA: (1)_____PSF ON BARE CONDUCTOR AT _____(6 psf MIN) FOR _____in. CLEARANCE

(2)_____PSF HIGH WIND ON BARE CONDUCTOR AT _____° F FOR _____in. CLEARANCE

ALLOWABLE SWING ANGLE: ANGLE IN DEGREES

	STRUCTURE. TYPE	NO. OF INSULATORS.	6 psf MIN. WIND(1)	HIGH WIND (2)	NO WIND	OTHER

X. ENVIRONMENTAL AND METEORLOGICAL DATA

TEMPERATURE: MIN_____° MAX._____°

AVERAGE YEARL LOW _____°

EXTREME 10 SEC. WIND GUSTS *(mph):*

10 YR. _____ 50 YR._____ 100 YR_____

MAXIMUM HEIGHT OF SNOW ON THE GROUND UNDER THE CONDUCTOR*(ft.)*:

CORROSIVENESS OF ATMOSPHERE:

DESCRIBE TERRAIN AND CHARACTERISTICS OF SOIL

XI. STRUCTURE DATA (FOR SINGLE POLES AND H-FRAMES*)*

POLE MATERIAL:_____

ARM MATERIAL: Trans_____

Underbuild_____

TYPE OF FOUNDATION: TANGENT:_____ANGLE:_____

DEADEND_____GUYED STRUCTURES_____

TANGENT STRUCTURE TYPE_____

SUMMARY OF SPANS *(ft.)* FOR TANGENT STRUCT.

	BASE POLE _____FT.____CL	OTHER HEIGHTS/CLASSES AND BRACING		
LEVEL GROUND SPAN				
MAX. HORIZON. SPAN LIMITED BY STRUCTURE STRENGTH				
MAX. VERTICAL SPAN LIMITED BY STRUCTURE STRENGTH				
MAX. HORIZONTAL SPAN LIMITED BY COND. SEPARATION				
MAX. SPAN LIMITED BY UNDERBUILD				
MAX. SPAN LIMITED BY GALLOPING				

EMBEDMENT DEPTH FOR BASE POLE:_____

PRESERVATIVE OF WOOD POLE (*TYPE &RETENT.*)_____

CORROSION PROTECTION FOR STEEL POLES _____

GUYING: TYPE OF ANCHORS: _____ GUY SIZE AND R.B.S.:_____

XII. LINE DESCRIPTION

TANGENTS_____%	LIGHT ANGLES _____%	AVERAGE NUMBER OF LINE ANGLES PER mi. _____
MEDIUM ANGLES_____%	DEADEND & HEAVY ANGLES_____%	MAXIMUM DISTANCE BETWEEN FULL DEADENDS (*mi.*)_____

INSTRUCTIONS FOR FILLING OUT SAMPLE SUMMARY SHEET

I. GENERAL INFORMATION

BORROWER – Agency borrower designation.

DATE – Date when design data was completed.

LINE IDENTIFICATION – The name of the line, usually expressed in terms of the line's endpoints. If the line design is "project design data" that is to be used for several line designs, the term "project design data" should be entered.

VOLTAGE – Nominal line-to-line voltage of both transmission and underbuild distribution circuit in kV. If there is no underbuild, fill in N. A. (not appropriate)

LENGTH – Self-explanatory.

TYPE OF TANGENT STRUCTURE – Give agency designation for tangent structure type used (for example, "TH-10"). If the structure is not a standard agency structure, the word "special" should be filled in.

BASE POLE – The height and class of pole used most widely in line.

DESIGNED BY – Individual and/or firm doing the designing.

II. CONDUCTOR DATA

SIZE – For conductors, size in AWG numbers or kcmil. For steel wire, diameter in inches.

STRANDING – Number of strands. For ACSR conductor, give aluminum first, steel second. For example: 26/7.

MATERIAL – Indicate conductor or wire type. For example, ACSR, 6201;or EHS (extra high strength steel).

DIAMETER – Diameter of conductor, in.

WEIGHT – Weight per foot of bare conductor, lbs/ft.

RATED STRENGTH – Standard rated strength of conductor.

III. DESIGN LOADS

NESC LOADING DISTRICT – Indicate the National Electrical Safety Code loading district on which design is based. Use "H" for heavy, "M" for medium, and "L" for light loading district.

a. Ice – Radial in. of ice on conductor for loading district specified.
b. Wind – Wind force in lbs. for loading district specified.
c. Constant "K" – Constant from NESC to be added to resultant of horizontal and vertical load (at standard loading district condition) for determining conductor sags and tensions.

HEAVY ICE – (no–wind, in.) – Radial thickness (in.) of ice conductor for the heavy icing condition for which line is designed (if any).

HIGH WIND – (no ice – psf) – The high wind value in lbs/sq. ft. for which the line is designed.

COMBINED EXTREME ICE/WIND – The loadings associated with the 50 yr extreme ice/wind from the figures in 11.3 of this bulletin. The radial thickness of ice and the unit loads should be given for the vertical loads. The high wind associated with the radial thickness of ice should be given for the tansverse loads as well as the unit loads.

LOADING TABLE - Conductor or wire loads in lbs. per linear ft. for conditions indicated at left.

IV. SAG & TENSION DATA

SPANS – AVG., MAX., and RULING – Self-explanatory.

SOURCE OF SAG-TENSION DATA – Self-explanatory.

TENSION TABLE – Initial and final tension values in percent of rated strength at loading conditions indicated on the left should be given. In those boxes where there is a dotted line in the center, the specified tension limiting values (in percent) should be given above the line. The actual resulting tension value (in percent) should be given below the line. For all other boxes the tension value should be the actual resulting value (in percent). The details of loading condition should be filled in on the left as follows:

a. Unloaded (0º, 15º, 30º) – Indicate appropriate temperature. Heavy loading district will be 0ºF, medium will be 15ºF, light will be, 30ºF.
b. NESC Loaded (0º, 15º, 30º) – Specify appropriate temperature.
c. Maximum Ice – Use the same maximum radial ice as indicated in the DESIGN LOADS section.
d. High Wind – Use the same value as in the DESIGN LOAD section.
e. Unloaded Low Temperature – Specify lowest temperature that can be expected to occur every winter.

SAG TABLE – Specify initial and/or final sags in ft. for conditions indicated. Specify maximum conductor operation temperature in the appropriate box on the left. Sags for the overhead ground wire and underbuild conductors are for a temperature of 120ºF.

Note: When sag and tension calculations are done, tension limits are usually specified at several conditions. However, only one of the conditions will usually control, resulting in tensions, at the other conditions, that are lower than the limit.

V. CLEARANCES

MINIMUM CLEARANCES TO BE MAINTAINED AT – Specify maximum sag condition at which minimum clearances are to be maintained. Generally, it will be at the high temperature condition but it may be possible for the sag at NESC loading (H, M, L) to be the controlling case.

CLEARANCE TABLE – Indicate clearance which will be used for plan and profile and design. Extra boxes are for special situations.

VI. RIGHT-OF-WAY WIDTH

Indicate width value used. If more than one value is used, give largest and smallest value.

VII. CONDUCTOR MOTION DATA

HISTORY OF CONDUCTOR GALLOPING – Indicate if conductor galloping has ever occurred in the area and how often it can be expected.

HISTORY OF AEOLIAN VIBRATION – Indicate whether or not the line is in an area prone to aeolian vibration.

a. Type of Vibration Dampers Used (if any) – Self-explanatory.
b. Type of Armor Rods Used (if any) – Indicate whether standard armor rods, cushioned suspension units or nothing is used.

VIII. INSULATION

NUMBER OF THUNDERSTORM DAYS/YEAR – Self -explanatory.

ELEVATION ABOVE SEA LEVEL (min., max., ft.) – Give the altitude in ft. above sea level of the minimum and maximum elevation points of the line

CONTAMINATION EXPECTED? – Indicate contamination problems which may affect the performance of the insulation. The following are recommended terms: None, Light, Medium, Heavy, Sea Coast Area.

MAXIMUM ESTIMATED FOOTING RESISTANCE. – Give the estimated maximum electrical footing resistance (in ohms) expected to be encountered along the length of the line. Where the footing resistance is high, the value to which the footing resistance will be reduced, by using special measures, should be indicated by putting this value in parentheses. For example, 70(20).

SHIELD ANGLE – If the basic tangent structure being used is not a standard structure, its shield angle should be given.

INSULATION TABLE – For the structure type indicated, the structure numerical designation and the number of suspension bells should be given. If post insulators are used instead of suspension, the word “post” or “pin” should be put in the second column. If nonceramic insulators are used, indicate ‘susp-nci’ or ‘post-nci’. The 60 Hz dry flashover value for the entire string of insulators (or post) should be given. The column “insulator size” should contain the diameter and length of the insulator. For suspension bell, the M&E strength should be given. For post insulator, the ultimate cantilever strength should be entered. For nonceramic insulators suspension or posts, give the SML ratings.

IX. INSULATOR SWING

CRITERIA – Self-explanatory

INSULATOR SWING TABLE – For the primary structures used in the line and the number of insulators used, the insulator swing angles under the 6 lb. minimum condition, the high wind condition and under the no wind condition should be given.. Angles measured from a vertical through the point of insulator string suspension away from structure should be indicated by following them with an asterisk (*).

X. ENVIRONMENTAL & METEORLOGICAL DATA

TEMPERATURE – The minimum, maximum, and average yearly low temperature recorded in the area of the line should be given.

MAXIMUM HEIGHT OF SNOW ON GROUND UNDER CONDUCTOR (ft.) – Self-explanatory.

CORROSIVENESS OF ATMOSPHERE – Indicate corrosiveness of the atmosphere by severe, moderate, or light.

EXTREME 10 SEC WIND GUSTS – Give the annual extreme wind with mean recurrence intervals of 10, 50, and 100 years. For 50 year, see Figures 11-2a to 11-2d of Chapter 11. For 10 year, see paragraph 7.2.3 of Chapter 7.

DESCRIBE TERRAIN & CHARACTER OF SOIL – A brief description should be given as to whether the terrain is flat, hilly, rolling piedmont, or mountainous. Indicate whether the soil firmness is good, average, or poor. Give approximate depth of ground water table. Describe corrosiveness of soil.

XI. STRUCTURE DATA (For single poles and H-frames)

POLE MATERIAL – Indicate wood, steel, or concrete. If wood, indicate species.

ARM MATERIAL – If a crossarm is used, indicate wood, steel or fiberglass..

TYPE OF FOUNDATION – For tangent, angle, or deadend structures, indicate direct embedded or caisson for the majority of the structures within each type. For example, if most of the angle and deadends are unguyed, indicate the predominant foundation for each type.

STRUCTURE TABLE The various maximum span values should be given for the base pole and structure configuration. Values should also be given for other pole heights, wood classes or standard steel/concrete pole classes, bracing and configurations that are expected to be commonly used.

a. **Level Ground Span** – Give the maximum span for height of pole, limited by clearance to ground only.
b. **Maximum Horizontal Span Limited by Structure Strength** – For single pole structures, give the maximum span as limited by pole strength. For H-frame structures, the effect of the bracing must be included. If vertical post insulators are used, their maximum horizontal span value should be included if it is less than that of the rest of the structure, and should be indicated as such by placing the term “ins” after the value. If underbuild is to be used on the line, its effect should be included.

c. **Maximum Vertical Span Limited by Structure Strength** – Give the maximum vertical span limited by either crossarm strength, crossarm brace strength, or horizontal post insulator strength. If horizontal post insulators are the limiting factor, the term "ins" should be placed after the span value. If the structure is such that the maximum horizontal span affects the maximum vertical span, the assumed maximum horizontal span should be the value shown in the "maximum horizontal span" box.
d. **Maximum Horizontal Span Limited by Conductor Separation** – Give the maximum span value from Equation 6-1 or 6-2 in Chapter 6 of this bulletin.
e. **Maximum Span Limited by Underbuild** – Give the maximum span limited by separation between underbuild conductors, or between underbuild and transmission conductors, whichever is more limited.
f. **Maximum Span Limited by Galloping** – Give the maximum span that can be allowed before galloping ellipses touch.

EMBEDMENT DEPTH – Indicate the pole embedment depth used. If the standard values are used, indicate "standard". If other values are use, indicate by how much they differ from the standard value. For example, std. + 2 ft.

PRESERVATIVE FOR WOOD POLES – Type and retention level of preservative.

CORROSION PROTECTION FOR STEEL POLES – Indicate weathering steel, galvanized steel, or painted.

GUYING – Indicate whether log, screw or other anchors are used and the predominant anchor capacity. For example: Log, 8,000/16,000 lbs. The diameter, type and rated breaking strength (rbs) of the guy strand should be given.

XII. LINE DESCRIPTION

For the respective structures types, indicate the percentage of the total number of structures used. Calculate the average number of line angles per mile and give the maximum distance in miles between full deadends: ("Full" deadends refer to strain type structures that are designed to remain standing if all conductors and overhead ground wires are cut on either side of the structure.)

SUGGESTED OUTLINE FOR
DESIGN DATA SUMMARY BOOK

Given below is a suggested outline for a Design Data Summary Book. The outline is primarily intended for lines of 230 kV Generally, a well prepared design data book should include all the material indicated below. However, some judgment should be used in submitting more or less information as deemed appropriate.

I. Transmission Line Design Data Summary

II. General Information

- A. Line identification, description and role in system
- B. Description of terrain and weather
- C. Design criteria and applicable codes and standards
- D. Selection of conductor and OHGW
  1. Selection of conductor and OHGW type
  2. Selection of conductor and OHGW size/ Economic conductor analysis
- E. Determination of maximum conductor temperature
- F. Selection of structure type and average height
  1. Economic evaluation of alternate structures
  2. Selection of optimum structure height
- G. Construction cost estimate

III. Supporting Calculations to Part I

- A. Conductor sag and tension tables (computer printout and source)
- B. OHGW sag and tension values (computer printout and source)
- C. Vertical and horizontal clearances and ROW width
- D. Insulation considerations
- E. Level ground span

F. Maximum span limited by conductor separation

   1. Horizontal separation

   2. Vertical and diagonal separation

G. Maximum span limited by underbuild (if applicable)

H. Galloping analysis

I. Unguyed structure strength calculations

   1. Maximum horizontal span limited by pole strength, 'X' bracing, poles (including post insulators; if applicable)

   2. Maximum vertical span limited by structure strength

   3. Loading trees for steel or concrete structures; selection method for standard class poles

   4. Hardware limitations

   5. Insulator strength requirements

   6. Foundation type; embedment depths; selection method; soil information

J. Guyed structure calculations

   1. Minimum spacing of anchors

   2. Guy and anchor calculations and application charts

   3. Maximum axial loads for guyed pole

   4. Guy attachments and their strengths

   5. Arrangement of guys and anchors and application guides

K. Sample insulator swing calculations and application charts for all structures

L. Diagrams for all non-standard structures or assemblies anticipated for use on the line

M. Sag-clearance template if a CADD program is not used for the plan-profile

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APPENDIX B

CONDUCTOR TABLES

- Conductor Mechanical Loading Tables B-2
- Overhead Ground Wire Loading Tables B-7

CONDUCTOR MECHANICAL LOADING TABLES

The tables that follow give horizontal, vertical, and resultant vector loads on conductors and overhead ground wires under standard NESC loading district conditions, high wind conditions, and heavy ice conditions.

ACSR CONDUCTORS
NESC DISTRICT LOADINGS

			LIGHT			MEDIUM			HEAVY					
			.00" ICE, 9 LB., K=.05			.25" ICE, 4 LB. WIND, K=.20			.5" ICE, 4 LB. WIND, K=.30			ULTIMATE		
			VERT.	TRANS	RESULTANT	VERT.	TRANS	RESULTANT	VERT.	TRANS	RESULTANT	STRENGTH	DIAM.	WT./FT.
NAME	SIZE	STRAND	LB/FT.	LB/FT.	LB/FT.	LB/FT.	LB/FT.	LB/FT.	LB/FT.	LB/FT.	LB/FT.	LBS.	IN.	LBS.
RAVEN	1/0	6/1	0.1452	0.2985	0.3819	0.3467	0.2993	0.6580	0.7036	0.4660	1.1439	4380	0.398	0.1452
QUAIL	2/0	6/1	0.1831	0.3353	0.4320	0.3998	0.3157	0.7094	0.7719	0.4823	1.2102	5310	0.447	0.1831
PIGEON	4/0	6/1	0.2309	0.3765	0.4917	0.4647	0.3340	0.7723	0.8539	0.5007	1.2899	6620	0.502	0.2309
PENGUIN	266.8	6/1	0.2911	0.4223	0.5629	0.5439	0.3543	0.8491	0.9520	0.5210	1.3853	8350	0.563	0.2911
WAXWING	266.8	18/1	0.2894	0.4568	0.5907	0.5565	0.3697	0.8681	0.9789	0.5363	1.4162	6880	0.609	0.2894
PARTRIDGE	336.4	26/7	0.3673	0.4815	0.6556	0.6446	0.3807	0.9486	1.0774	0.5473	1.5084	11300	0.642	0.3673
MERLIN	336.4	18/1	0.3653	0.5130	0.6798	0.6557	0.3947	0.9653	1.1015	0.5613	1.5363	8680	0.684	0.3653
LINNET	336.4	26/7	0.4630	0.5408	0.7619	0.7649	0.4070	1.0664	1.2222	0.5737	1.6501	14100	0.721	0.4630
ORIOLE	397.5	30/7	0.5271	0.5558	0.8160	0.8352	0.4137	1.1320	1.2987	0.5803	1.7225	17300	0.741	0.5271
CHICKADEE	397.5	18/1	0.4316	0.5573	0.7548	0.7403	0.4143	1.0484	1.2045	0.5810	1.6373	9940	0.743	0.4316
IBIS	397.5	26/7	0.5469	0.5873	0.8525	0.8680	0.4277	1.1677	1.3446	0.5943	1.7701	16300	0.783	0.5469
LARK	397.5	30/7	0.6228	0.6045	0.9179	0.9511	0.4353	1.2460	1.4348	0.6020	1.8560	20300	0.806	0.6228
PELICAN	477.	18/1	0.5180	0.6105	0.8506	0.8488	0.4380	1.1551	1.3350	0.6047	1.7656	11800	0.814	0.5180
FLICKER	477.	24/7	0.6145	0.6345	0.9333	0.9552	0.4487	1.2554	1.4514	0.6153	1.8765	17200	0.846	0.6145
HAWK	477.	26/7	0.6570	0.6435	0.9696	1.0015	0.4527	1.2990	1.5014	0.6193	1.9241	19500	0.858	0.6570
HEN	477.	30/7	0.7470	0.6623	1.0483	1.0992	0.4610	1.3920	1.6069	0.6277	2.0251	23800	0.883	0.7470
OSPREY	556.5	18/1	0.6040	0.6593	0.9441	0.9550	0.4597	1.2599	1.4614	0.6263	1.8900	13700	0.879	0.6040
PARAKEET	556.5	24/7	0.7170	0.6855	1.0420	1.0789	0.4713	1.3773	1.5962	0.6380	2.0190	19800	0.914	0.7170
DOVE	556.5	26/7	0.7660	0.6953	1.0845	1.1319	0.4757	1.4278	1.6533	0.6423	2.0737	22600	0.927	0.7660
EAGLE	556.5	30/7	0.8720	0.7148	1.1775	1.2460	0.4843	1.5368	1.7754	0.6510	2.1910	27800	0.953	0.8720
KINGBIRD	636.	18/1	0.6910	0.7050	1.0372	1.0610	0.4800	1.3645	1.5864	0.6467	2.0131	15700	0.940	0.6910
ROOK	636.	24/7	0.8190	0.7478	1.1590	1.2067	0.4990	1.5058	1.7498	0.6657	2.1721	22000	0.997	0.8190
GOSBEAK	636.	26/7	0.8750	0.7425	1.1976	1.2605	0.4967	1.5548	1.8014	0.6633	2.2197	25200	0.990	0.8750
EGRET	636.	30/19	0.9880	0.7643	1.2991	1.3825	0.5063	1.6723	1.9325	0.6730	2.3463	31500	1.019	0.9880
CUCKOO	795.	24/7	1.0240	0.8190	1.3612	1.4412	0.5307	1.7358	2.0139	0.6973	2.4312	27900	1.092	1.0240
DRAKE	795.	26/7	1.0940	0.8310	1.4238	1.5162	0.5360	1.8081	2.0938	0.7027	2.5086	31500	1.108	1.0940
MALLARD	795.	30/19	1.2350	0.8550	1.5521	1.6671	0.5467	1.9545	2.2547	0.7133	2.6649	38400	1.140	1.2350
TERN	795.	45/7	0.8960	0.7973	1.2493	1.3042	0.5210	1.6044	1.8678	0.6877	2.2904	22100	1.063	0.8960
CONDOR	795.	54/7	1.0240	0.8198	1.3617	1.4415	0.5310	1.7362	2.0145	0.6977	2.4319	28200	1.093	1.0240
RAIL	954.	45/7	1.0750	0.8738	1.4353	1.5149	0.5550	1.8134	2.1103	0.7217	2.5302	25900	1.165	1.0750
CARDINAL	954.	54/7	1.2290	0.8970	1.5715	1.6785	0.5653	1.9712	2.2835	0.7320	2.6980	33800	1.196	1.2290
BUNTING	1192.5	45/7	1.3440	0.9765	1.7113	1.8265	0.6007	2.1227	2.4644	0.7673	2.8811	3200	1.302	1.3440
GRACKLE	1192.5	54/19	1.5330	1.0035	1.8822	2.0267	0.6127	2.3173	2.6758	0.7793	3.0870	41900	1.338	1.5330
BITTERN	1272.	45/7	1.4340	1.0088	1.8033	1.9299	0.6150	2.2255	2.5812	0.7817	2.9969	34100	1.345	1.4340
PHEASANT	1272.	54/19	1.6350	1.0365	1.9859	2.1424	0.6273	2.4323	2.8052	0.7940	3.2154	43600	1.382	1.6350
LAPWING	1590.	45/7	1.7920	1.1265	2.1667	2.3367	0.6673	2.6301	3.0368	0.8340	3.4492	42200	1.502	1.7920
FALCON	1590.	54/19	2.0440	1.1588	2.3996	2.6020	0.6817	2.8898	3.3155	0.8483	3.7223	54500	1.545	2.0440
CHUKAR	1780.	84/19	2.0740	1.2015	2.4469	2.6498	0.7007	2.9408	3.3810	0.8673	3.7904	51000	1.602	2.0740
BLUEBIRD	2156.	84/19	2.5110	1.3215	2.8875	3.1365	0.7540	3.4259	3.9175	0.9207	4.3242	60300	1.762	2.5110

ACSR CONDUCTORS
HIGH WIND LOADINGS

				13 psf		16 psf		21 psf		26 psf		31 psf		6 psf	
NAME	SIZE	STRAND	WT./FT LBS.	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	SWING ANGLE
RAVEN	1/0	6/1	0.1452	0.4312	0.4550	0.5307	0.5502	0.6965	0.7115	0.8623	0.8745	1.0282	1.0384	0.1990	53.88
QUAIL	2/0	6/1	0.1831	0.4843	0.5177	0.5960	0.6235	0.7823	0.8034	0.9685	0.9857	1.1548	1.1692	0.2235	50.67
PIGEON	4/0	6/1	0.2309	0.5438	0.5908	0.6693	0.7080	0.8785	0.9083	1.0877	1.1119	1.2968	1.3172	0.2510	47.39
PENGUIN	266.8	6/1	0.2911	0.6099	0.6758	0.7507	0.8051	0.9853	1.0274	1.2198	1.2541	1.4544	1.4833	0.2815	44.04
WAXWING	266.8	18/1	0.2894	0.6598	0.7204	0.8120	0.8620	1.0658	1.1043	1.3195	1.3509	1.5733	1.5996	0.3045	46.46
PARTRIDGE	336.4	26/7	0.3673	0.6955	0.7865	0.8560	0.9315	1.1235	1.1820	1.3910	1.4387	1.6585	1.6987	0.3210	41.15
MERLIN	336.4	18/1	0.3653	0.7410	0.8262	0.9120	0.9824	1.1970	1.2515	1.4820	1.5264	1.7670	1.8044	0.3420	43.11
LINNET	336.4	26/7	0.4630	0.7811	0.9080	0.9613	1.0670	1.2618	1.3440	1.5622	1.6293	1.8626	1.9193	0.3605	37.90
ORIOLE	397.5	30/7	0.5271	0.8028	0.9603	0.9880	1.1198	1.2968	1.3998	1.6055	1.6898	1.9143	1.9855	0.3705	35.10
CHICKADEE	397.5	18/1	0.4316	0.8049	0.9133	0.9907	1.0806	1.3003	1.3700	1.6098	1.6667	1.9194	1.9673	0.3715	40.72
IBIS	397.5	26/7	0.5469	0.8483	1.0093	1.0440	1.1786	1.3703	1.4754	1.6965	1.7825	2.0228	2.0954	0.3915	35.60
LARK	397.5	30/7	0.6228	0.8732	1.0725	1.0747	1.2421	1.4105	1.5419	1.7463	1.8541	2.0822	2.1733	0.4030	32.91
PELICAN	477.	18/1	0.5180	0.8818	1.0227	1.0853	1.2026	1.4245	1.5158	1.7637	1.8382	2.1028	2.1657	0.4070	38.16
FLICKER	477.	24/7	0.6145	0.9165	1.1034	1.1280	1.2845	1.4805	1.6030	1.8330	1.9333	2.1855	2.2702	0.4230	34.54
HAWK	477.	26/7	0.6570	0.9295	1.1383	1.1440	1.3192	1.5015	1.6389	1.8590	1.9717	2.2165	2.3118	0.4290	33.14
HEN	477.	30/7	0.7470	0.9566	1.2137	1.1773	1.3943	1.5453	1.7163	1.9132	2.0538	2.2811	2.4003	0.4415	30.58
OSPREY	556.5	18/1	0.6040	0.9523	1.1277	1.1720	1.3185	1.5383	1.6526	1.9045	1.9980	2.2708	2.3497	0.4395	36.04
PARAKEET	556.5	24/7	0.7170	0.9902	1.2225	1.2187	1.4139	1.5995	1.7529	1.9803	2.1061	2.3612	2.4676	0.4570	32.51
DOVE	556.5	26/7	0.7660	1.0043	1.2630	1.2360	1.4541	1.6223	1.7940	2.0085	2.1496	2.3948	2.5143	0.4635	31.18
EAGLE	556.5	30/7	0.8720	1.0324	1.3514	1.2707	1.5411	1.6678	1.8820	2.0648	2.2414	2.4619	2.6118	0.4765	28.65
KINGBIRD	636.	18/1	0.6910	1.0183	1.2306	1.2533	1.4312	1.6450	1.7842	2.0367	2.1507	2.4283	2.5247	0.4700	34.22
ROOK	636.	24/7	0.8190	1.0801	1.3555	1.3293	1.5614	1.7448	1.9274	2.1602	2.3102	2.5756	2.7027	0.4985	31.33
GOSBEAK	636.	26/7	0.8750	1.0725	1.3842	1.3200	1.5837	1.7325	1.9409	2.1450	2.3166	2.5575	2.7030	0.4950	29.50
EGRET	636.	30/19	0.9880	1.1039	1.4815	1.3587	1.6799	1.7833	2.0387	2.2078	2.4188	2.6324	2.8117	0.5095	27.28
CUCKOO	795.	24/7	1.0240	1.1830	1.5646	1.4560	1.7800	1.9110	2.1681	2.3660	2.5781	2.8210	3.0011	0.5460	28.07
DRAKE	795.	26/7	1.0940	1.2003	1.6241	1.4773	1.8383	1.9390	2.2263	2.4007	2.6382	2.8623	3.0643	0.5540	26.86
MALLARD	795.	30/19	1.2350	1.2350	1.7466	1.5200	1.9585	1.9950	2.3463	2.4700	2.7615	2.9450	3.1935	0.5700	24.78
TERN	795.	45/7	0.8960	1.1516	1.4591	1.4173	1.6768	1.8603	2.0648	2.3032	2.4713	2.7461	2.8886	0.5315	30.68
CONDOR	795.	54/7	1.0240	1.1841	1.5654	1.4573	1.7811	1.9128	2.1696	2.3682	2.5801	2.8236	3.0035	0.5465	28.09
RAIL	954.	45/7	1.0750	1.2621	1.6579	1.5533	1.8890	2.0388	2.3048	2.5242	2.7435	3.0096	3.1958	0.5825	28.45
CARDINAL	954.	54/7	1.2290	1.2957	1.7858	1.5947	2.0133	2.0930	2.4272	2.5913	2.8680	3.0897	3.3251	0.5980	25.95
BUNTING	1192.5	45/7	1.3440	1.4105	1.9483	1.7360	2.1955	2.2785	2.6454	2.8210	3.1248	3.3635	3.6221	0.6510	25.84
GRACKLE	1192.5	54/19	1.5330	1.4495	2.1098	1.7840	2.3522	2.3415	2.7987	2.8990	3.2794	3.4565	3.7812	0.6690	23.58
BITTERN	1272.	45/7	1.4340	1.4571	2.0444	1.7933	2.2962	2.3538	2.7562	2.9142	3.2479	3.4746	3.7589	0.6725	25.13
PHEASANT	1272.	54/19	1.6350	1.4972	2.2169	1.8427	2.4635	2.4185	2.9193	2.9943	3.4116	3.5702	3.9267	0.6910	22.91
LAPWING	1590.	45/7	1.7920	1.6272	2.4205	2.0027	2.6874	2.6285	3.1812	3.2543	3.7151	3.8802	4.2740	0.7510	22.74
FALCON	1590.	54/19	2.0440	1.6738	2.6419	2.0600	2.9020	2.7038	3.3894	3.3475	3.9222	3.9913	4.4842	0.7725	20.70
CHUKAR	1780.	84/19	2.0740	1.7355	2.7043	2.1360	2.9772	2.8035	3.4873	3.4710	4.0434	4.1385	4.6291	0.8010	21.12
BLUEBIRD	2156.	84/19	2.5110	1.9088	3.1542	2.3493	3.4387	3.0835	3.9766	3.8177	4.5694	4.5518	5.1985	0.8810	19.33

ACSR CONDUCTORS
MISCELLANEOUS LOADINGS

NAME	SIZE	STRAND	DIAM. IN.	WT./FT LBS.	0.75 INCH ICE WT./FT LBS.	1PSF TRANS LB/FT	1 INCH ICE WT./FT LBS.	1PSF TRANS LB/FT	1.25 INCH ICE WT./FT LBS.	1PSF TRANS LB/FT
RAVEN	1/0	6/1	0.398	0.1452	1.2159	0.1582	1.8837	0.1998	2.7069	0.2415
QUAIL	2/0	6/1	0.447	0.1831	1.2995	0.1623	1.9825	0.2039	2.8210	0.2456
PIGEON	4/0	6/1	0.502	0.2309	1.3986	0.1668	2.0987	0.2085	2.9543	0.2502
PENGUIN	266.8	6/1	0.563	0.2911	1.5157	0.1719	2.2348	0.2136	3.1093	0.2553
WAXWING	266.8	18/1	0.609	0.2894	1.5569	0.1758	2.2903	0.2174	3.1791	0.2591
PARTRIDG	336.4	26/7	0.642	0.3673	1.6656	0.1785	2.4092	0.2202	3.3083	0.2618
MERLIN	336.4	18/1	0.684	0.3653	1.7027	0.1820	2.4594	0.2237	3.3716	0.2653
LINNET	336.4	26/7	0.721	0.4630	1.8349	0.1851	2.6031	0.2268	3.5268	0.2684
ORIOLE	397.5	30/7	0.741	0.5271	1.9177	0.1868	2.6921	0.2284	3.6220	0.2701
CHICKADI	397.5	18/1	0.743	0.4316	1.8241	0.1869	2.5991	0.2286	3.5296	0.2703
IBIS	397.5	26/7	0.783	0.5469	1.9767	0.1903	2.7641	0.2319	3.7071	0.2736
LARK	397.5	30/7	0.806	0.6228	2.0740	0.1922	2.8686	0.2338	3.8187	0.2755
PELICAN	477.	18/1	0.814	0.5180	1.9767	0.1928	2.7738	0.2345	3.7264	0.2762
FLICKER	477.	24/7	0.846	0.6145	2.1030	0.1955	2.9101	0.2372	3.8726	0.2788
HAWK	477.	26/7	0.858	0.6570	2.1567	0.1965	2.9675	0.2382	3.9337	0.2798
HEN	477.	30/7	0.883	0.7470	2.2700	0.1986	3.0886	0.2403	4.0626	0.2819
OSPREY	556.5	18/1	0.879	0.6040	2.1233	0.1983	2.9406	0.2399	3.9134	0.2816
PARAKEE	556.5	24/7	0.914	0.7170	2.2689	0.2012	3.0971	0.2428	4.0808	0.2845
DOVE	556.5	26/7	0.927	0.7660	2.3301	0.2023	3.1623	0.2439	4.1500	0.2856
EAGLE	556.5	30/7	0.953	0.8720	2.4603	0.2044	3.3006	0.2461	4.2964	0.2878
KINGBIRD	636.	18/1	0.940	0.6910	2.2672	0.2033	3.1035	0.2450	4.0952	0.2867
ROOK	636.	24/7	0.997	0.8190	2.4484	0.2081	3.3024	0.2498	4.3118	0.2914
GOSBEAK	636.	26/7	0.990	0.8750	2.4978	0.2075	3.3497	0.2492	4.3569	0.2908
EGRET	636.	30/19	1.019	0.9880	2.6379	0.2099	3.4987	0.2516	4.5150	0.2933
CUCKOO	795.	24/7	1.092	1.0240	2.7420	0.2160	3.6255	0.2577	4.6645	0.2993
DRAKE	795.	26/7	1.108	1.0940	2.8269	0.2173	3.7154	0.2590	4.7594	0.3007
MALLARD	795.	30/19	1.140	1.2350	2.9977	0.2200	3.8962	0.2617	4.9501	0.3033
TERN	795.	45/7	1.063	0.8960	2.5869	0.2136	3.4614	0.2553	4.4914	0.2969
CONDOR	795.	54/7	1.093	1.0240	2.7429	0.2161	3.6267	0.2578	4.6660	0.2994
RAIL	954.	45/7	1.165	1.0750	2.8610	0.2221	3.7673	0.2638	4.8290	0.3054
CARDINAL	954.	54/7	1.196	1.2290	3.0440	0.2247	3.9598	0.2663	5.0311	0.3080
BUNTING	1192.5	45/7	1.302	1.3440	3.2578	0.2335	4.2066	0.2752	5.3109	0.3168
GRACKLE	1192.5	54/19	1.338	1.5330	3.4804	0.2365	4.4404	0.2782	5.5559	0.3198
BITTERN	1272.	45/7	1.345	1.4340	3.3879	0.2371	4.3501	0.2788	5.4678	0.3204
PHEASAN	1272.	54/19	1.382	1.6350	3.6234	0.2402	4.5971	0.2818	5.7263	0.3235
LAPWING	1590.	45/7	1.502	1.7920	3.8924	0.2502	4.9034	0.2918	6.0698	0.3335
FALCON	1590.	54/19	1.545	2.0440	4.1845	0.2538	5.2088	0.2954	6.3886	0.3371
CHUKAR	1780.	84/19	1.602	2.0740	4.2676	0.2585	5.3097	0.3002	6.5072	0.3418
BLUEBIRD	2156.	84/19	1.762	2.5110	4.8538	0.2718	5.9457	0.3135	7.1930	0.3552

Transverse loadings are based on 1 psf on the indicated ice condition. Transverse loadings other than 1psf can be obtained by multiplying the transverse loading value in the table by the amount of the expected wind load

For example, the transverse load caused by a 6 psf wind on a 477 kcmil 26/7 conductor covered by 1 inch of radial ice is:

.2382(6) = 1.4292 lb/ft.

6201 ALUMINUM ALLOY CONDUCTORS
NESC DISTRICT LOADINGS

			LIGHT			MEDIUM			HEAVY		
			.00" ICE, 9 LB., K=.05			.25" ICE, 4 LB WIND, K=.20			.5" ICE, 4 LB WIND, K=.30		
			VERT.	TRANS	RESULTANT	VERT.	TRANS	RESULTANT	VERT.	TRANS	RESULTANT
NAME	SIZE	STRAND	LB/FT	LB/FT	LB/FT	LB/FT	LB/FT	LB/FT	LB/FT	LB/FT	LB/FT
AZUSA	123.3	7	0.1157	0.2985	0.3701	0.3172	0.2993	0.6361	0.6741	0.4660	1.1195
ANAHEIM	155.4	7	0.1459	0.3353	0.4156	0.3626	0.3157	0.6807	0.7347	0.4823	1.1789
AMHERST	195.7	7	0.1837	0.3765	0.4689	0.4175	0.3340	0.7347	0.8067	0.5007	1.2495
ALLIANCE	246.9	7	0.2318	0.4223	0.5317	0.4846	0.3543	0.8003	0.8927	0.5210	1.3337
BUTTE	312.8	19	0.2936	0.4815	0.6140	0.5709	0.3807	0.8862	1.0037	0.5473	1.4432
CANTON	394.5	19	0.3703	0.5408	0.7054	0.6722	0.4070	0.9858	1.1295	0.5737	1.5668
CAIRO	465.4	19	0.4369	0.5873	0.7819	0.7580	0.4277	1.0704	1.2346	0.5943	1.6702
DARIEN	559.5	19	0.5252	0.6435	0.8806	0.8697	0.4527	1.1804	1.3696	0.6193	1.8031
ELOIN	652.4	19	0.6124	0.6953	0.9765	0.9783	0.4757	1.2878	1.4997	0.6423	1.9314
FLINT	740.8	37	0.6954	0.7433	1.0678	1.0812	0.4970	1.3900	1.6225	0.6637	2.0530
GREELEY	927.2	37	0.8704	0.8310	1.2534	1.2926	0.5360	1.5993	1.8702	0.7027	2.2979

6201 ALUMINUM ALLOY CONDUCTORS
HIGH WIND LOADINGS

				13 psf		16 psf		21 psf		26 psf		31 psf	
			WT./FT	TRANS	RESULTANT	TRANS	RESULTANT	TRANS	RESULTANT	TRANS	RESULTANT	TRANS	RESULTANT
NAME	SIZE	STRAND	LBS.	LB/FT	LB/FT	LB/FT	LB/FT	LB/FT	LB/FT	LB/FT	LB/FT	LB/FT	LB/FT
AZUSA	123.3	7	0.1157	0.4312	0.4464	0.5307	0.5431	0.6965	0.7060	0.8623	0.8701	1.0282	1.0347
ANAHEIM	155.4	7	0.1459	0.4843	0.5058	0.5960	0.6136	0.7823	0.7957	0.9685	0.9794	1.1548	1.1639
AMHERST	195.7	7	0.1837	0.5438	0.5740	0.6693	0.6941	0.8785	0.8975	1.0877	1.1031	1.2968	1.3098
ALLIANCE	246.9	7	0.2318	0.6099	0.6525	0.7507	0.7856	0.9853	1.0122	1.2198	1.2417	1.4544	1.4728
BUTTE	312.8	19	0.2936	0.6955	0.7549	0.8560	0.9050	1.1235	1.1612	1.3910	1.4216	1.6585	1.6843
CANTON	394.5	19	0.3703	0.7811	0.8644	0.9613	1.0302	1.2618	1.3150	1.5622	1.6055	1.8626	1.8990
CAIRO	465.4	19	0.4369	0.8483	0.9542	1.0440	1.1317	1.3703	1.4382	1.6965	1.7519	2.0228	2.0694
DARIEN	559.5	19	0.5252	0.9295	1.0676	1.1440	1.2588	1.5015	1.5907	1.8590	1.9318	2.2165	2.2779
ELOIN	652.4	19	0.6124	1.0043	1.1762	1.2360	1.3794	1.6223	1.7340	2.0085	2.0998	2.3948	2.4718
FLINT	740.8	37	0.6954	1.0736	1.2791	1.3213	1.4932	1.7343	1.8685	2.1472	2.2570	2.5601	2.6528
GREELEY	927.2	37	0.8704	1.2003	1.4827	1.4773	1.7147	1.9390	2.1254	2.4007	2.5536	2.8623	2.9917

6201 ALUMINUM ALLOY CONDUCTORS - MISCELLANEOUS LOADINGS

			0.75 " ICE		1.0 " ICE		1.25 " ICE		
			WT./FT	TRANS	WT./FT	TRANS	WT./FT	TRANS	
NAME	SIZE	STRAND	LBS.	for 1psf	LBS.	for 1psf	LBS.	for 1psf	Transverse Loadings other than 1 psf on the indicated ice
				LB/FT		LB/FT		LB/FT	
AZUSA	123.3	7	1.1864	0.1582	1.8542	0.1998	2.6774	0.2415	condition can be obtained by multiplying the transverse l
ANAHEIM	155.4	7	1.2623	0.1623	1.9453	0.2039	2.7838	0.2456	value in the table by the amount of the expected wind loa
AMHERST	195.7	7	1.3514	0.1668	2.0515	0.2085	2.9071	0.2502	per foot.
ALLIANCE	246.9	7	1.4564	0.1719	2.1755	0.2136	3.0500	0.2553	
BUTTE	312.8	19	1.5919	0.1785	2.3355	0.2202	3.2346	0.2618	For example, the transverse load caused by a 6 psf wind
CANTON	394.5	19	1.7422	0.1851	2.5104	0.2268	3.4341	0.2684	wind on a 559.5 kcmil conductor covered by 1 inch of rac
CAIRO	465.4	19	1.8667	0.1903	2.6541	0.2319	3.5971	0.2736	
DARIEN	559.5	19	2.0249	0.1965	2.8357	0.2382	3.8020	0.2798	.2382(6) = 1.4292 lb/ft.
ELOIN	652.4	19	2.1765	0.2023	3.0087	0.2439	3.9964	0.2856	
FLINT	740.8	37	2.3192	0.2076	3.1713	0.2493	4.1789	0.2909	
GREELEY	927.2	37	2.6033	0.2173	3.4918	0.2590	4.5358	0.3007	

1350 ALUMINUM ALLOY CONDUCTORS
NESC DISTRICT LOADINGS

			LIGHT .00" ICE, 9 LB., K=.05			MEDIUM .25" ICE, 4 LB WIND, K=.20			HEAVY .5" ICE, 4 LB WIND, K=.30			ULTIMATE		
NAME	SIZE	STRAND	VERT. LB/FT	TRANS LB/FT	RESULTANT LB/FT	VERT. LB/FT	TRANS LB/FT	RESULTANT LB/FT	VERT. LB/FT	TRANS LB/FT	RESULTANT LB/FT	STRENGTH LBS.	DIAM. IN.	WT./FT LBS.
POPPY	1/0	7	0.0991	0.2760	0.3433	0.2912	0.2893	0.6105	0.6388	0.4560	1.0849	1990	0.368	0.0991
ASTRE	2/0	7	0.1249	0.3105	0.3847	0.3313	0.3047	0.6501	0.6932	0.4713	1.1383	2510	0.414	0.1249
PHLOX	3/0	7	0.1575	0.3480	0.4320	0.3795	0.3213	0.6972	0.7569	0.4880	1.2006	3040	0.464	0.1575
OXLIP	4/0	7	0.1986	0.3915	0.4890	0.4386	0.3407	0.7554	0.8341	0.5073	1.2762	3830	0.522	0.1986
VALERIAN	250.	19	0.2347	0.4305	0.5403	0.4909	0.3580	0.8076	0.9025	0.5247	1.3439	4660	0.574	0.2347
DAISY	266.8	7	0.2505	0.4395	0.5559	0.5104	0.3620	0.8257	0.9257	0.5287	1.3661	4830	0.586	0.2505
LAUREL	266.8	19	0.2505	0.4448	0.5604	0.5126	0.3643	0.8289	0.9301	0.5310	1.3710	4970	0.593	0.2505
TULIP	336.4	19	0.3128	0.4995	0.6394	0.5976	0.3887	0.9128	1.0378	0.5553	1.4770	6150	0.666	0.3128
CANNA	397.5	19	0.3731	0.5430	0.7088	0.6759	0.4080	0.9895	1.1342	0.5747	1.5714	7110	0.724	0.3731
GOLDENTUFT	450.	19	0.4224	0.5775	0.7655	0.7395	0.4233	1.0521	1.2121	0.5900	1.6480	7890	0.770	0.4224
COSMOS	477.	19	0.4478	0.5948	0.7945	0.7721	0.4310	1.0842	1.2518	0.5977	1.6871	8360	0.793	0.4478
SYRINGA	477.	37	0.4478	0.5963	0.7957	0.7727	0.4317	1.0851	1.2530	0.5983	1.6885	8690	0.795	0.4478
DAHLIA	556.5	19	0.5220	0.6420	0.8774	0.8658	0.4520	1.1767	1.3651	0.6187	1.7988	9750	0.856	0.5220
MISTLETOE	556.5	37	0.5220	0.6435	0.8786	0.8665	0.4527	1.1776	1.3664	0.6193	1.8002	9940	0.858	0.5220
ORCHID	636.	37	0.5970	0.6885	0.9613	0.9601	0.4727	1.2702	1.4787	0.6393	1.9110	11400	0.918	0.5970
ARBUTUS	795.	37	0.7460	0.7695	1.1217	1.1427	0.5087	1.4508	1.6948	0.6753	2.1244	13900	1.026	0.7460
LILAC	795.	61	0.7460	0.7710	1.1228	1.1433	0.5093	1.4516	1.6961	0.6760	2.1258	14300	1.028	0.7460
ANEMONE	874.5	37	0.8210	0.8078	1.2017	1.2335	0.5257	1.5409	1.8015	0.6923	2.2300	15000	1.077	0.8210
CROCUS	874.5	61	0.8210	0.8085	1.2023	1.2339	0.5260	1.5413	1.8022	0.6927	2.2307	15800	1.078	0.8210
MAGNOLIA	954.	37	0.8960	0.8430	1.2802	1.3232	0.5413	1.6296	1.9058	0.7080	2.3330	16400	1.124	0.8960
GOLDENROD	954.	61	0.8960	0.8445	1.2813	1.3238	0.5420	1.6304	1.9070	0.7087	2.3344	16900	1.126	0.8960
HAWTHORN	1192.5	61	1.1190	0.9435	1.5137	1.5878	0.5860	1.8925	2.2121	0.7527	2.6366	21100	1.258	1.1190
NARCESSUS	1272.	61	1.1920	0.9750	1.5900	1.6739	0.6000	1.9782	2.3112	0.7667	2.7350	22000	1.300	1.1920
COREOPSIS	1590	61	1.4900	1.0898	1.8960	2.0194	0.6510	2.3218	2.7043	0.8177	3.1252	27000	1.453	1.4900

1350 ALUMINUM ALLOY CONDUCTORS
HIGH WIND LOADINGS

				13 psf		16 psf		21 psf		26 psf		31 psf		6 psf	
NAME	SIZE	STRAND	WT./FT LBS.	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	SWING ANGLE
POPPY	1/0	7	0.0991	0.3987	0.4108	0.4907	0.5006	0.6440	0.6516	0.7973	0.8035	0.9507	0.9558	0.1840	61.7
ASTER	2/0	7	0.1249	0.4485	0.4656	0.5520	0.5660	0.7245	0.7352	0.8970	0.9057	1.0695	1.0768	0.2070	58.9
PHLOX	3/0	7	0.1575	0.5027	0.5268	0.6187	0.6384	0.8120	0.8271	1.0053	1.0176	1.1987	1.2090	0.2320	55.8
OXLIP	4/0	7	0.1986	0.5655	0.5994	0.6960	0.7238	0.9135	0.9348	1.1310	1.1483	1.3485	1.3630	0.2610	52.7
DAISY	266.8	7	0.2505	0.6348	0.6825	0.7813	0.8205	1.0255	1.0557	1.2697	1.2941	1.5138	1.5344	0.2930	49.5
LAUREL	266.8	19	0.2505	0.6424	0.6895	0.7907	0.8294	1.0378	1.0676	1.2848	1.3090	1.5319	1.5523	0.2965	49.8
TULIP	336.4	19	0.3128	0.7215	0.7864	0.8880	0.9415	1.1655	1.2067	1.4430	1.4765	1.7205	1.7487	0.3330	46.8
CANNA	397.5	19	0.3731	0.7843	0.8686	0.9653	1.0349	1.2670	1.3208	1.5687	1.6124	1.8703	1.9072	0.3620	44.1
GOLDENTUFT	450.	19	0.4224	0.8342	0.9350	1.0267	1.1102	1.3475	1.4122	1.6683	1.7210	1.9892	2.0335	0.3850	42.3
COSMOS	477.	19	0.4478	0.8591	0.9688	1.0573	1.1483	1.3878	1.4582	1.7182	1.7756	2.0486	2.0970	0.3965	41.5
SYRINGA	477.	37	0.4478	0.8613	0.9707	1.0600	1.1507	1.3913	1.4615	1.7225	1.7798	2.0538	2.1020	0.3975	41.6
DAHLIA	556.5	19	0.5220	0.9273	1.0642	1.1413	1.2550	1.4980	1.5863	1.8547	1.9267	2.2113	2.2721	0.4280	39.3
MISTLETOE	556.5	37	0.5220	0.9295	1.0660	1.1440	1.2575	1.5015	1.5896	1.8590	1.9309	2.2165	2.2771	0.4290	39.4
ORCHID	636.	37	0.5970	0.9945	1.1599	1.2240	1.3618	1.6065	1.7138	1.9890	2.0767	2.3715	2.4455	0.4590	37.6
ARBUTUS	795.	37	0.7460	1.1115	1.3386	1.3680	1.5582	1.7955	1.9443	2.2230	2.3448	2.6505	2.7535	0.5130	34.5
LILAC	795.	61	0.7460	1.1137	1.3404	1.3707	1.5605	1.7990	1.9475	2.2273	2.3489	2.6557	2.7585	0.5140	34.6
ANEMONE	874.5	37	0.8210	1.1668	1.4267	1.4360	1.6541	1.8848	2.0558	2.3335	2.4737	2.7823	2.9009	0.5385	33.3
CROCUS	874.5	61	0.8210	1.1678	1.4275	1.4373	1.6553	1.8865	2.0574	2.3357	2.4758	2.7848	2.9033	0.5390	33.3
MAGNOLIA	954.	37	0.8960	1.2177	1.5118	1.4987	1.7461	1.9670	2.1615	2.4353	2.5949	2.9037	3.0388	0.5620	32.1
GOLDENROD	954.	61	0.8960	1.2198	1.5135	1.5013	1.7484	1.9705	2.1646	2.4397	2.5990	2.9088	3.0437	0.5630	32.1
HAWTHORN	1192.5	61	1.1190	1.3628	1.7634	1.6773	2.0163	2.2015	2.4696	2.7257	2.9464	3.2498	3.4371	0.6290	29.3
NARCESSUS	1272.	61	1.1920	1.4083	1.8451	1.7333	2.1036	2.2750	2.5684	2.8167	3.0585	3.3583	3.5636	0.6500	28.6
COREOPSIS	1590	61	1.1940	1.5741	1.9757	1.9373	2.2757	2.5428	2.8091	3.1482	3.3670	3.7536	3.9389	0.7265	31.3

1350 ALUMINUM ALLOY CONDUCTORS
MISCELLANEOUS LOADINGS

NAME	SIZE	STRAND	DIAM. IN.	WT./FT LBS.	.75 " ICE WT./FT LBS.	.75 " ICE TRANS for 1psf LB/FT	1.0 " ICE WT./FT LBS.	1.0 " ICE TRANS for 1psf LB/FT	1.25 " ICE WT./FT LBS.	1.25 " ICE TRANS for 1psf LB/FT
POPPY	1/0	7	0.368	0.0991	1.1418	0.1557	1.8003	0.1973	2.6142	0.2390
ASTRE	2/0	7	0.414	0.1249	1.2105	0.1595	1.8833	0.2012	2.7115	0.2428
PHLOX	3/0	7	0.464	0.1575	1.2898	0.1637	1.9781	0.2053	2.8218	0.2470
OXLIP	4/0	7	0.522	0.1986	1.3849	0.1685	2.0913	0.2102	2.9531	0.2518
VALERIAN	250.	19	0.574	0.2347	1.4695	0.1728	2.1920	0.2145	3.0700	0.2562
DAISY	266.8	7	0.586	0.2505	1.4965	0.1738	2.2228	0.2155	3.1044	0.2572
LAUREL	266.8	19	0.593	0.2505	1.5031	0.1744	2.2315	0.2161	3.1153	0.2578
TULIP	336.4	19	0.666	0.3128	1.6335	0.1805	2.3846	0.2222	3.2911	0.2638
CANNA	397.5	19	0.724	0.3731	1.7478	0.1853	2.5170	0.2270	3.4416	0.2687
GOLDENTUFT	450.	19	0.770	0.4224	1.8400	0.1892	2.6235	0.2308	3.5624	0.2725
COSMOS	477.	19	0.793	0.4478	1.8869	0.1911	2.6775	0.2328	3.6235	0.2744
SYRINGA	477.	37	0.795	0.4478	1.8888	0.1913	2.6800	0.2329	3.6266	0.2746
DAHLIA	556.5	19	0.856	0.5220	2.0199	0.1963	2.8300	0.2380	3.7956	0.2797
MISTLETOE	556.5	37	0.858	0.5220	2.0217	0.1965	2.8325	0.2382	3.7988	0.2798
ORCHID	636.	37	0.918	0.5970	2.1527	0.2015	2.9821	0.2432	3.9670	0.2848
ARBUTUS	795.	37	1.026	0.7460	2.4024	0.2105	3.2654	0.2522	4.2839	0.2938
LILAC	795.	61	1.028	0.7460	2.4043	0.2107	3.2679	0.2523	4.2870	0.2940
ANEMONE	874.5	37	1.077	0.8210	2.5250	0.2148	3.4039	0.2564	4.4382	0.2981
CROCUS	874.5	61	1.078	0.8210	2.5259	0.2148	3.4051	0.2565	4.4397	0.2982
MAGNOLIA	954.	37	1.124	0.8960	2.6438	0.2187	3.5373	0.2603	4.5862	0.3020
GOLDENROD	954.	61	1.126	0.8960	2.6457	0.2188	3.5398	0.2605	4.5893	0.3022
HAWTHORN	1192.5	61	1.258	1.1190	2.9918	0.2298	3.9269	0.2715	5.0175	0.3132

		LIGHT .00" ICE, 9 LB., K=.05			MEDIUM .25" ICE, 4 LB WIND, K=.20			HEAVY .5" ICE, 4 LB WIND, K=.30			ULTIMATE
SIZE	STRAND	VERT. LB/FT	TRANS LB/FT	RESULTANT LB/FT	VERT. LB/FT	TRANS LB/FT	RESULTANT LB/FT	VERT. LB/FT	TRANS LB/FT	RESULTANT LB/FT	STRENGTH LBS.
3/8	7	0.2730	0.2700	0.4340	0.4626	0.2867	0.7443	0.8077	0.4533	1.2262	10800
7/16	7	0.3990	0.3263	0.5654	0.6120	0.3117	0.8868	0.9804	0.4783	1.3908	14500
3/8	7	0.2730	0.2700	0.4340	0.4626	0.2867	0.7443	0.8077	0.4533	1.2262	15400
7/16	7	0.3990	0.3263	0.5654	0.6120	0.3117	0.8868	0.9804	0.4783	1.3908	20800
7 NO. 9		0.2076	0.2573	0.3806	0.3920	0.2810	0.6823	0.7318	0.4477	1.1578	12630
7 NO. 8		0.2618	0.2888	0.4398	0.4592	0.2950	0.7458	0.8121	0.4617	1.2341	15930
7 NO. 7		0.3300	0.3248	0.5130	0.5423	0.3110	0.8252	0.9101	0.4777	1.3278	19060

OVERHEAD GROUND WIRES
HIGH WIND LOADINGS

			13 psf		16 psf		21 psf		26 psf		31 psf		6 psf	
SIZE	STRAND	WT./FT LBS.	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	RESULTANT LB/FT	TRANS LB/FT	SWING ANGLE
3/8	7	0.2730	0.3900	0.4761	0.4800	0.5522	0.6300	0.6866	0.7800	0.8264	0.9300	0.9692	0.1800	33.4
7/16	7	0.3990	0.4713	0.6175	0.5800	0.7040	0.7613	0.8595	0.9425	1.0235	1.1238	1.1925	0.2175	28.6
3/8	7	0.2730	0.3900	0.4761	0.4800	0.5522	0.6300	0.6866	0.7800	0.8264	0.9300	0.9692	0.1800	33.4
7/16	7	0.3990	0.4713	0.6175	0.5800	0.7040	0.7613	0.8595	0.9425	1.0235	1.1238	1.1925	0.2175	28.6
7 NO. 9		0.2076	0.3716	0.4256	0.4573	0.5022	0.6003	0.6351	0.7432	0.7716	0.8861	0.9101	0.1715	39.6
7 NO. 8		0.2618	0.4171	0.4924	0.5133	0.5762	0.6738	0.7228	0.8342	0.8743	0.9946	1.0285	0.1925	36.3
7 NO. 7		0.3300	0.4691	0.5735	0.5773	0.6650	0.7578	0.8265	0.9382	0.9945	1.1186	1.1662	0.2165	33.3

OVERHEAD GROUND WIRES - MISCELLANEOUS LOADINGS

		0.75 " ICE		1.0 " ICE		1.25 " ICE	
SIZE	STRAND	WT./FT LBS.	TRANS for 1psf LB/FT	WT./FT LBS.	TRANS for 1psf LB/FT	WT./FT LBS.	TRANS for 1psf LB/FT
3/8	7	1.3083	0.1550	1.9642	0.1967	2.7756	0.2383
7/16	7	1.5042	0.1613	2.1835	0.2029	3.0182	0.2446
3/8	7	1.3083	0.1550	1.9642	0.1967	2.7756	0.2383
7/16	7	1.5042	0.1613	2.1835	0.2029	3.0182	0.2446
7 NO. 9		1.2270	0.1536	1.8777	0.1953	2.6838	0.2369
7 NO. 8		1.3204	0.1571	1.9841	0.1988	2.8033	0.2404
7 NO. 7		1.4333	0.1611	2.1120	0.2028	2.9461	0.2444

Transverse Loadings other than 1 psf on the indicated ice

condition can be obtained by multiplying the transverse loading value in the table by the amount of the expected wind load per foot.

For example, the transverse load caused by a 6 psf wind on 3/8" HIGH STRENGTH STEEL OHGW covered by 1 inch of radial ice is:

.1967(6) = 1.1802 lb/ft.

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APPENDIX C

INSULATION TABLES

- Flashover Data For Porcelain String
  5-3/4”X 10” Standard Suspension Insulators C-2
- Flashover Data For Suspension Polymers
  ANSI C29.12-1997 C-3
- Approximate Weights and Length of Insulator Strings Using
  Standard 5-3/4 in. x 10 in. Suspension Bells C-4

TABLE C-1

FLASHOVER DATA FOR PORCELAIN STRING
5-3/4"X 10" STANDARD SUSPENSION INSULATORS

Units in string	60Hz Flashover-kV		Impulse Flashover, kV 1.5 X 50	
	Dry	Wet	Positive	Negative
2	155	90	250	250
3	215	130	355	340
4	270	170	440	415
5	325	215	525	495
6	380	255	610	585
7	435	295	695	670
8	485	335	780	760
9	540	375	860	845
10	590	415	945	930
11	640	455	1025	1015
12	690	490	1105	1105
13	735	525	1185	1190
14	785	565	1265	1275
15	830	600	1345	1360
16	875	630	1425	1440
17	920	660	1505	1530
18	965	690	1585	1615
19	1010	720	1665	1700
20	1055	750	1745	1785
21	1095	775	1820	1865
22	1135	800	1895	1945
23	1175	825	1970	2025
24	1215	850	2045	2105
25	1255	875	2120	2185

TABLE C-2

FLASHOVER DATA FOR SUSPENSION POLYMERS
(ANSI C29.12-1997)

ANSI Class	Electrical Values			
	Low Frequency flashover		Critical Impulse Flashover	
	Dry (kV)	Wet (kV)	Positive (kV)	Negative (kV)
60-1	365	310	610	585
60-2	410	350	675	670
60-3	470	415	780	760
60-4	485	455	860	845
60-5	560	490	925	930
60-6	620	545	1025	1015
60-7	670	580	1105	1105
60-8	720	620	1185	1190
60-9	810	690	1345	1360
60-10	900	755	1490	1530
60-11	925	795	1575	1600
60-12	980	830	1665	1700
60-13	1060	890	1825	1870
60-14	1345	1290	2530	2630

TABLE C-3

APPROXIMATE WEIGHTS AND LENGTHS OF
INSULATOR STRINGS USING STANDARD
5-3/4" x 10" SUSPENSION BELLS WITH A BALL HOOK*

Number of Insulators	Length of String (Includes Suspension Hardware), Ft.	Weight of String (Includes Suspension Hardware), Lbs.	Max. Voltage- for the Number of Insulators (Tangent)
3	2.00	45	34.5 kV, 46 kV
4	2.50	58	69 kV
5	3.00	71	
6	3.50	84	
7	3.92	96	115 kV
8	4.42	109	
9	4.92	122	
10	5.33	135	161 kV
11	5.83	147	
12	6.33	160	230 kV
13	6.83	173	
14	7.25	186	
15	7.75	198	
16	8.25	211	

*Exact length and weight will vary slightly depending upon conductor suspension hardware used.

APPENDIX D

AMPACITY, MVA, SURFACE GRADIENT TABLES

- Ampacity Of ACSR Conductors D-2
- MVA Limits D-3

TABLE D-1
AMPACITY OF ACSR CONDUCTORS

Conductor Temperature			120ºF	167ºF	212ºF				
Summer ambient			104ºF	104ºF	104ºF				
Winter ambient			32ºF	32ºF	32ºF				
Wind (ft./sec.)			2	2	2	ft./sec.			
			Ampacity Summer Rating			**Ampacity Winter Rating**			
NAME	**SIZE**	**STRAND**	**120 Deg F**	**167 Deg F**	**212 Deg F**	**120 Deg F**	**167 Deg F**	**212 Deg F**	
RAVEN	1/0	6/1	70	195	257	240	292	330	
QUAIL	2/0	6/1	77	223	294	275	335	379	
PIGEON	3/0	6/1	85	255	338	315	384	435	
PENGUIN	4/0	6/1	92	291	386	357	439	497	
WAXWING	266.8	18/1	110	359	478	442	543	616	
PARTRIDGE	266.8	26/7	108	364	484	447	550	624	
MERLIN	336.4	18/1	119	416	554	511	630	715	
LINNET	336.4	26/7	117	420	561	517	637	724	
ORIOLE	397.5	30/7	115	423	565	520	642	729	
CHICKADEE	397.5	18/1	120	461	616	544	700	795	
IBIS	397.5	26/7	122	466	624	574	708	806	
LARK	397.5	30/7	120	469	629	578	714	812	
PELICAN	477.	18/1	131	516	692	636	786	894	
FLICKER	477.	24/7	128	521	699	641	793	902	
HAWK	477.	26/7	127	522	701	644	796	906	
HEN	477.	30/7	124	526	706	648	801	913	
OSPREY	556.5	18/1	135	568	763	700	866	986	
PARAKEET	556.5	24/7	130	573	771	706	874	996	
DOVE	556.5	26/7	129	575	774	709	878	1000	
EAGLE	556.5	30/7	126	579	779	713	884	1007	
KINGBIRD	636.	18/1	136	617	815	761	943	1053	
ROOK	636.	24/7	131	623	839	768	952	1085	
GOSBEAK	636.	26/7	129	625	843	770	955	1089	
EGRET	636.	30/19	125	629	849	776	962	1097	
CUCKOO	795.	24/7	126	715	967	882	1096	1251	
DRAKE	795.	26/7	123	718	972	886	1101	1257	
MALLARD	795.	30/19	116	723	979	892	1110	1267	
TERN	795.	45/7	131	709	959	874	1086	1240	
CONDOR	795.	54/7	126	715	967	882	1096	1251	
RAIL	954.	45/7	120	793	1076	978	1218	1393	
CARDINAL	954.	54/7	112	800	1086	987	1229	1406	
BUNTING	1192.5	45/7	84	908	1238	1121	1400	1604	
GRACKLE	1192.5	54/19	65	927	1264	1144	1429	1637	
BITTERN	1272.	45/7	61	944	1289	1165	1457	1670	
PHEASANT	1272.	54/19	21	964	1317	1190	1489	1706	
LAPWING	1590.	45/7		1079	1480	1330	1670	1919	
FALCON	1590.	54/19		1103	1514	1361	1709	1963	
CHUKAR	1780.	84/19		1168	1608	1440	1813	2085	
BLUEBIRD	2156	84/19		1304	1803	1606	2030	2340	

TABLE D-2: MVA LIMITS

CONDUCTOR			MVA LIMIT FOR 212 DEGREE F OPERATION AT THE INDICATED VOLTAGE (S = Summer; W = Winter)													
			34.5 kV		46 kV		69 kV		115 kV		138 kV		161 kV		230 KV	
NAME	SIZE & STRAND		S	W	S	W	S	W	S	W	S	W	S	W	S	W
RAVEN	1/0	6/1	15	20	20	26	31	39	51	66	61	79	72	92	102	132
QUAIL	2/0	6/1	18	23	23	30	35	45	59	75	70	91	82	106	117	151
PIGEON	3/0	6/1	20	26	27	35	40	52	67	87	81	104	94	121	134	173
PENGUIN	4/0	6/1	23	30	31	40	46	59	77	99	92	119	108	139	154	198
WAXWING	266.8	18/1	29	37	38	49	57	74	95	123	114	147	133	172	190	245
PARTRIDGE	266.8	26/7	29	37	39	50	58	75	96	124	116	149	135	174	193	249
MERLIN	336.4	18/1	33	43	44	57	66	85	110	142	132	171	155	199	221	285
LINNET	336.4	26/7	34	43	45	58	67	87	112	144	134	173	156	202	224	288
ORIOLE	397.5	30/7	34	44	45	58	68	87	113	145	135	174	158	203	225	290
CHICKADEE	397.5	18/1	37	48	37	48	74	95	123	158	147	190	172	222	246	317
IBIS	397.5	26/7	37	48	37	48	75	96	124	160	149	193	174	225	249	321
LARK	397.5	30/7	38	48	38	48	75	97	125	162	150	194	175	226	250	323
PELICAN	477.	18/1	41	53	41	53	83	107	138	178	165	214	193	249	276	356
FLICKER	477.	24/7	42	54	42	54	83	108	139	180	167	216	195	252	278	359
HAWK	477.	26/7	42	54	42	54	84	108	140	180	168	216	196	253	279	361
HEN	477.	30/7	42	55	42	55	84	109	141	182	169	218	197	254	281	364
OSPREY	556.5	18/1	46	59	46	59	91	118	152	196	182	236	213	275	304	393
PARAKEET	556.5	24/7	46	60	46	60	92	119	154	198	184	238	215	278	307	397
DOVE	556.5	26/7	46	60	46	60	93	120	154	199	185	239	216	279	308	398
EAGLE	556.5	30/7	47	60	47	60	93	120	155	201	186	241	217	281	310	401
KINGBIRD	636.	18/1	49	63	49	63	97	126	162	210	195	252	227	294	324	419
ROOK	636.	24/7	50	65	50	65	100	130	167	216	201	259	234	303	334	432
GOSBEAK	636.	26/7	50	65	50	65	101	130	168	217	201	260	235	304	336	434
EGRET	636.	30/19	51	66	51	66	101	131	169	219	203	262	237	306	338	437
CUCKOO	795.	24/7	58	75	58	75	116	150	193	249	231	299	270	349	385	498
DRAKE	795.	26/7	58	75	58	75	116	150	194	250	232	301	271	351	387	501
MALLARD	795.	30/19	59	76	59	76	117	151	195	252	234	303	273	353	390	505
TERN	795.	45/7	57	74	57	74	115	148	191	247	229	296	267	346	382	494
CONDOR	795.	54/7	58	75	58	75	116	150	193	249	231	299	270	349	385	498
RAIL	954.	45/7	64	83	64	83	129	166	214	277	257	333	300	388	429	555
CARDINAL	954.	54/7	65	84	65	84	130	168	216	280	260	336	303	392	433	560
BUNTING	1192.5	45/7	74	96	74	96	148	192	247	319	296	383	345	447	493	639
GRACKLE	1192.5	54/19	76	98	76	98	151	196	252	326	302	391	352	457	504	652
BITTERN	1272.	45/7	77	100	77	100	154	200	257	333	308	399	359	466	514	665
PHEASANT	1272.	54/19	79	102	79	102	157	204	262	340	315	408	367	476	525	680
LAPWING	1590.	45/7	88	115	88	115	177	229	295	382	354	459	413	535	590	764
FALCON	1590.	54/19	90	117	90	117	181	235	302	391	362	469	422	548	603	782
CHUKAR	1780.	84/19	96	125	96	125	192	249	320	415	384	498	448	581	640	831
BLUEBIRD	2156	84/19	108	140	108	140	215	280	359	466	431	559	503	653	718	932

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APPENDIX E

WEATHER DATA

- Wind Velocities and Pressures E-2
- Conversion Factors for Other Mean Recurrence Intervals E-3
- Map of Isokeraunic Levels for the United States E-4

TABLE E-1
WIND VELOCITIES AND PRESSURES

Actual Wind Velocity, mi/hr.	psf on a Cylindrical Surface	psf on a Flat Surface
35	3.1	4.8
40	4.0	6.3
45	5.2	8.1
49	6.0	9.6
50	6.4	10.0
55	7.7	12.0
60	9.0	14.1
65	10.8	16.9
70	12.5	19.5
75	14.4	22.5
80	16.4	28.9
85	18.5	32.3
90	20.7	36.1
95	23.1	40.0
100	25.6	44.1
105	28.2	48.4
110	31.0	53.0
115	33.9	57.7
120	36.9	63.1

*Based on:

$F = .00256V^2$ (for cylindrical surfaces)

Where:

F= wind force in pounds per square foot.

V= wind velocity in miles per hour.

TABLE E-2
CONVERSION FACTORS FOR OTHER
MEAN RECURRENCE INTERVALS

MRI (years)	Peak gust wind speed, V (mph)		
	Continental U.S.		
	V=85-100	V>100 (hurricane)	Alaska
500	1.23	1.23	1/18
200	1.14	1.14	1.12
100	1.07	1.07	1.06
50	1.00	1.00	1.00
25	0.93	0.88	0.94
10	0.84	0.74(76 mph min.)	0.87
5	0.78	0.66(60 mph min.)	0.81

Note:
Conversion factors for the column "V>100 (hurricane)" are approximate. For the MRI (mean recurrence interval) = 50 as shown, the actual return period, as represented by the design wind speed map in Figures 11-2a to 11-2d, varies from 50 to approximately 90 years. For an MRI = 500, the conversion factor is theoretically "exact" as shown.

TABLE E-3
PROBABLILITY OF EXCEEDING DESIGN WIND SPEEDS
DURING REFERENCE PERIOD

Annual Probablility P_a	Reference (Exposure) Period, *n* (years)					
	1	5	10	25	50	100
.04(1/25)	0.04	0.18	0.34	0.64	0.87	0.98
.02(1/50)	0.02	0.10	0.18	0.40	0.64	0.87
.01(1/100)	0.01	0.05	0.10	0.22	0.40	0.64
.005(1/200)	0.005	0.02	0.05	0.10	0.22	0.39

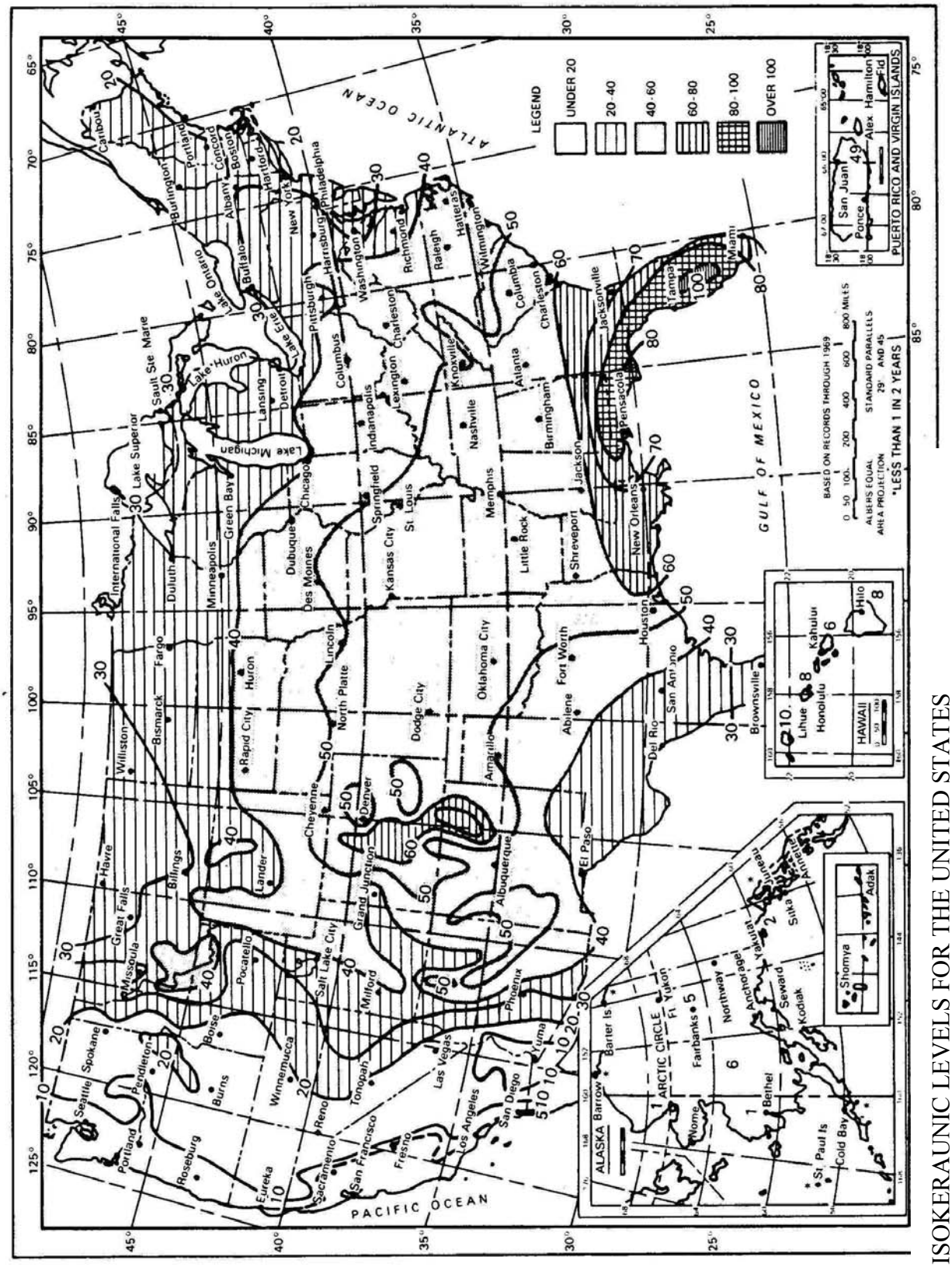


FIGURE E-1: ISOKERAUNIC LEVELS FOR THE UNITED STATES

APPENDIX F

POLE DATA

- Moments (ft-k) at Groundline Due to a 1 psf Wind on the Pole F-2
- Moment Capacities for Wood Poles at Groundline F-3
- Pole Classes F-4
- Moment Capacities for D.F. and SYP Along the Pole F-5
- Moment Reduction due to a Bolt Hole in the Pole F-20
- Weight and Volume of D.F. and SYP Poles F-22

TABLE F-1
MOMENTS (FT-K) AT GROUNDLINE
DUE TO A 1 PSF WIND ON THE POLE

	6000 psi Western Red Cedar				6600 psi Lodgepole Pine			
Ht.	**Cl-H1**	**Cl-1**	**Cl-2**	**Cl-3**	**Cl-H1**	**Cl-1**	**Cl-2**	**Cl-3**
50	0.9	0.9	0.8	0.7		0.8	0.8	0.7
55	1.1	1.0	1.0	0.9		1.0	1.0	0.9
60	1.4	1.3	1.2	1.1		1.3	1.2	1.1
65	1.6	1.5	1.4	1.3		1.5	1.4	1.3
70	1.9	1.8	1.7	1.6		1.8	1.7	1.5
75	2.2	2.1	2.0	1.8		2.1	1.9	1.8
80	2.6	2.4	2.3	2.1		2.4	2.2	2.1
85	3.0	2.8	2.6	2.4		2.7	2.5	2.4
90	3.4	3.2	3.0	2.7		3.1	2.9	2.7
95	3.9	3.6	3.4			3.6	3.3	
100	4.4	4.1	3.8			4.0	3.7	

	8000 psi Douglas Fir and Southern Yellow Pine				8400 psi Western Larch			
Ht.	**Cl-H1**	**Cl-1**	**Cl-2**	**Cl-3**	**Cl-H1**	**Cl-1**	**Cl-2**	**Cl-3**
50	0.9	0.8	0.8	0.7	0.9	0.8	0.8	0.7
55	1.1	1.0	0.9	0.9	1.1	1.0	0.9	0.9
60	1.3	1.2	1.1	1.1	1.3	1.2	1.1	1.0
65	1.6	1.5	1.4	1.3	1.6	1.4	1.4	1.2
70	1.8	1.7	1.6	1.5	1.8	1.7	1.6	1.5
75	2.1	2.0	1.9	1.7	2.1	2.0	1.8	1.7
80	2.5	2.3	2.2	2.0	2.5	2.3	2.1	2.0
85	2.8	2.6	2.5	2.3	2.8	2.6	2.4	2.3
90	3.2	3.0	2.8	2.6	3.2	3.0	2.8	2.6
95	3.7	3.4	3.2		3.6	3.4	3.2	
100	4.2	3.9	3.6		4.1	3.9	3.6	

TABLE F-2
MOMENT CAPACITIES (FT-K) AT GROUNDLINE
For Western Red Cedar (6000 psi), Lodgepole Pine (6600 psi),
Douglas Fir and Southern Yellow Pine (8000 psi) and Western Larch (8400 psi)

6000 psi Western Red Cedar					6600 psi Lodgepole Pine				
Ht.	ClassH1	Class 1	Class 2	Class 3		Class 1	Class 2	Class 3	Ht.
50	222.2	186.1	154.2	126.2		186.9	153.9	125.1	50
55	245.4	206.9	172.7	137.9		202.5	167.8	137.2	55
60	270.4	229.3	192.7	150.4		225.5	182.5	150.2	60
65	297.1	246.7	202.4	163.7		243.4	198.2	159.0	65
70	317.7	265.1	218.6	177.9		262.4	214.8	173.4	70
75	339.4	284.4	235.7	192.9		282.4	232.4	188.8	75
80	362.2	304.8	253.8	203.1		303.4	251.0	205.1	80
85	386.1	326.2	266.0	219.6		317.5	263.6	216.1	85
90	411.1	348.6	285.6	230.7		340.4	283.8	227.5	90
95	441.6	367.3	301.9			368.0	300.5		95
100	473.4	395.5	326.6			387.8	317.7		100

8000 psi Douglas Fir & Southern Yellow Pine					8400 psi Western Larch				
Ht.	ClassH1	Class 1	Class 2	Class 3	ClassH1	Class 1	Class 2	Class 3	Ht.
50	220.3	187.2	152.1	121.7	222.4	183.9	148.7	123.0	50
55	246.4	204.2	167.1	134.7	243.6	201.1	163.8	136.4	55
60	266.8	222.3	183.0	148.7	264.3	219.4	179.9	145.4	60
65	288.4	241.5	200.0	163.5	294.4	238.9	203.5	160.4	65
70	311.2	261.9	218.1	179.4	318.0	259.5	215.3	176.4	70
75	335.3	283.4	230.3	190.2	333.8	281.3	227.7	187.3	75
80	360.6	306.2	250.2	201.5	359.6	296.1	247.8	198.7	80
85	387.2	321.5	263.7	213.3	386.7	320.0	261.5	210.6	85
90	405.2	337.5	285.5	225.5	405.0	336.2	275.8	229.9	90
95	438.0	357.3	303.2		438.3	365.6	301.5		95
100	461.5	387.3	321.5		462.1	386.7	319.9		100

TABLE F-3
POLE CLASSES

Wood poles are separated into 15 classes based on the minimum circumference of the pole 6 feet from the butt. The minimum circumferences have been calculated in order for each species (in a given class) to develop stresses approximately equal to those shown in the table. These stresses are developed at the groundline, when a horizontal load is applied 2 feet from the top of the pole. The horizontal loads used in these calculations are as follows:

Class	Horizontal Load (lbs.)
H6	11,400
H5	10,000
H4	8,700
H3	7,500
H2	6,400
H1	5,400
1	4,500
2	3,700
3	3,000
4	2,400
5	1,900
6	1,500
7	1,200
9	740
10	370

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

55 ft. 55 ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.36	68.87	53.7	8.72	59.73	43.4	1	8.08	51.25	34.5	7.43	43.41	26.9	1
2	9.50	70.84	56.1	8.85	61.48	45.3	2	8.20	52.79	36.1	7.55	44.75	28.2	2
3	9.63	72.84	58.5	8.97	63.26	47.3	3	8.32	54.34	37.7	7.66	46.11	29.4	3
4	9.76	74.87	60.9	9.10	65.05	49.3	4	8.44	55.93	39.3	7.78	47.49	30.8	4
5	9.90	76.93	63.4	9.23	66.88	51.4	5	8.56	57.53	41.0	7.89	48.89	32.1	5
6	10.03	79.01	66.0	9.35	68.73	53.6	6	8.68	59.16	42.8	8.00	50.31	33.6	6
7	10.16	81.12	68.7	9.48	70.60	55.8	7	8.80	60.81	44.6	8.12	51.75	35.0	7
8	10.30	83.26	71.4	9.61	72.5	58.0	8	8.92	62.48	46.4	8.23	53.20	36.5	8
9	10.43	85.43	74.3	9.73	74.42	60.4	9	9.04	64.17	48.3	8.34	54.68	38.0	9
10	10.56	87.63	77.1	9.86	76.37	62.8	10	9.16	65.89	50.3	8.46	56.18	39.6	10
11	10.70	89.85	80.1	9.99	78.35	65.2	11	9.28	67.63	52.5	8.57	57.71	41.2	11
12	10.83	92.10	83.1	10.11	80.35	67.7	12	9.40	69.40	54.4	8.69	59.25	42.9	12
13	10.96	94.38	86.2	10.24	82.37	70.3	13	9.52	71.18	56.5	8.80	60.81	44.6	13
14	11.10	96.69	89.4	10.37	84.42	72.9	14	9.64	72.99	58.6	8.91	62.39	46.3	14
15	11.23	99.02	92.7	10.49	86.50	75.6	15	9.76	74.82	60.9	9.03	63.99	48.1	15
16	11.36	101.39	96.0	10.62	88.60	78.4	16	9.88	76.68	63.1	9.14	65.61	50.0	16
17	11.49	103.78	99.4	10.75	90.73	81.3	17	10.00	78.55	65.5	9.25	67.25	51.9	17
18	11.63	106.19	102.9	10.87	92.88	84.2	18	10.12	80.45	67.9	9.37	68.92	53.8	18
19	11.76	108.64	106.5	11.00	95.05	87.1	19	10.24	82.37	70.3	9.48	70.60	55.8	19
20	11.89	111.12	110.1	11.13	92.26	90.2	20	10.36	84.32	72.8	9.59	72.30	57.8	20
21	12.03	113.62	113.9	11.25	99.48	93.3	21	10.48	86.29	75.4	9.71	74.03	59.9	21
22	12.16	116.15	117.7	11.38	101.73	96.5	22	10.60	88.28	78.0	9.82	75.77	62.0	22
23	12.29	118.71	121.6	11.51	104.01	99.7	23	10.72	90.29	80.7	9.94	77.53	64.2	23
24	12.43	121.29	125.6	11.63	106.31	103.1	24	10.84	92.32	83.4	10.05	79.32	66.4	24
25	12.56	123.90	129.7	11.76	108.64	106.5	25	10.96	94.38	86.2	10.16	81.12	68.7	25
26	12.69	126.55	133.9	11.89	110.99	110.0	26	11.08	96.46	89.1	10.28	82.95	71.0	26
27	12.83	129.21	138.1	12.01	113.37	113.5	27	11.20	98.57	92.0	10.39	84.79	73.4	27
28	12.96	131.91	142.5	12.14	115.78	117.1	28	11.32	100.69	95.0	10.50	86.66	75.9	28
29	13.09	134.64	146.9	12.27	118.20	120.8	29	11.44	102.84	98.1	10.62	88.55	78.3	29
30	13.23	137.39	151.4	12.39	120.66	124.6	30	11.56	105.01	101.2	10.73	90.45	80.9	30
31	13.36	140.17	156.0	12.52	123.14	128.5	31	11.68	107.21	104.4	10.85	92.38	83.5	31
32	13.49	142.98	160.8	12.65	125.64	132.4	32	11.80	109.42	107.6	10.96	94.33	86.1	32
33	13.63	145.81	165.6	12.77	128.17	136.4	33	11.92	111.66	111.0	11.07	96.29	88.9	33
34	13.76	148.68	170.5	12.90	130.72	140.5	34	12.04	113.92	114.3	11.19	98.28	91.6	34
35	13.89	151.57	175.5	13.03	133.30	144.7	35	12.16	116.21	117.8	11.30	100.29	94.4	35
36	14.03	154.49	180.6	13.15	135.91	149.0	36	12.28	118.52	121.3	11.41	102.32	97.3	36
37	14.16	157.44	185.8	13.28	138.54	153.3	37	12.40	120.85	124.9	11.53	104.36	100.3	37
38	14.29	160.41	191.0	13.41	141.19	157.8	38	12.52	123.20	128.6	11.64	106.43	103.2	38
39	14.42	163.42	196.4	13.53	143.87	162.3	39	12.64	125.58	132.3	11.75	108.52	106.3	39
40	14.56	166.45	201.9	13.66	146.58	166.9	40	12.76	127.97	136.1	11.87	110.63	109.4	40
41	14.69	169.51	207.5	13.79	149.31	171.6	41	12.89	130.40	140.0	11.98	112.76	112.6	41
42	14.82	172.60	213.2	13.91	152.07	176.3	42	13.01	132.84	144.0	12.10	114.91	115.8	42
43	14.96	175.71	219.0	14.04	154.85	181.2	43	13.13	135.31	148.0	12.21	117.08	119.1	43
44	15.09	178.85	224.9	14.17	157.66	186.1	44	13.25	137.79	152.1	12.32	119.27	122.5	44
45	15.22	182.02	230.9	14.29	160.49	191.2	45	13.37	140.31	156.3	12.44	121.48	125.9	45
46	15.36	185.22	237.0	14.42	163.34	196.3	46	13.49	142.84	160.5	12.55	123.71	129.4	46
47	15.49	188.45	243.3	14.55	166.23	201.5	47	13.61	145.40	164.9	12.66	125.96	132.9	47
48	15.62	191.70	249.6	14.67	169.13	206.8	48	13.73	147.98	169.3	12.78	128.24	136.5	48
49	15.76	194.98	256.0	14.80	172.07	212.2	49	13.85	150.58	173.8	12.89	130.53	140.2	49
50	15.82	196.64	259.3	14.87	173.62	215.1	50	13.91	152.04	176.3	12.96	131.88	142.4	50
51	15.89	198.31	262.6	14.94	175.19	218.0	51	13.98	153.50	178.8	13.03	133.25	144.6	51
52	15.96	199.98	265.9	15.00	176.76	221.0	52	14.05	154.97	181.4	13.09	134.62	146.9	52
53	16.02	201.66	269.3	15.07	178.34	223.9	53	14.11	156.45	184.0	13.16	136.00	149.1	53
54	16.09	203.34	272.7	15.14	179.92	226.9	54	14.18	157.94	186.6	13.23	137.38	151.4	54
55	16.16	205.04	276.1	15.20	181.52	230.0	55	14.25	159.43	189.3	13.29	138.77	153.7	55

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

60 ft. 60 ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
0	9.231	66.92	51.5	8.594	58.01	41.5	0	7.958	49.74	33.0	7.32	42.10	25.7	0
1	9.361	68.82	53.7	8.718	59.70	43.4	1	8.076	51.22	34.5	7.43	43.39	26.9	1
2	9.49	70.74	55.9	8.842	61.40	45.2	2	8.194	52.73	36.0	7.55	44.71	28.1	2
3	9.62	72.68	58.3	8.966	63.13	47.2	3	8.311	54.26	37.6	7.66	46.05	29.4	3
4	9.75	74.66	60.7	9.09	64.89	49.2	4	8.429	55.81	39.2	7.77	47.41	30.7	4
5	9.879	76.66	63.1	9.213	66.67	51.2	5	8.547	57.38	40.9	7.88	48.78	32.0	5
6	10.01	78.68	65.6	9.337	68.47	53.3	6	8.665	58.97	42.6	7.99	50.18	33.4	6
7	10.14	80.73	68.2	9.461	70.30	55.4	7	8.783	60.59	44.3	8.11	51.60	34.8	7
8	10.27	82.81	70.9	9.585	72.15	57.6	8	8.901	60.22	46.2	8.22	53.03	36.3	8
9	10.4	84.92	73.6	9.708	74.03	59.9	9	9.019	63.88	48.0	8.33	54.49	37.8	9
10	10.53	87.05	76.4	9.832	75.93	62.2	10	9.137	65.56	49.9	8.44	55.96	39.4	10
11	10.66	89.21	79.2	9.956	77.85	64.6	11	9.255	67.27	51.9	8.55	57.46	41.0	11
12	10.79	91.39	82.2	10.08	79.80	67.0	12	9.372	68.99	53.9	8.67	58.97	42.6	12
13	10.92	93.60	85.2	10.2	81.77	69.5	13	9.49	70.74	55.9	8.78	60.51	44.3	13
14	11.05	95.84	88.2	10.33	83.77	72.1	14	9.608	72.51	58.1	8.89	62.06	46.0	14
15	11.18	98.10	91.4	10.45	85.79	74.7	15	9.726	74.30	60.2	9.00	63.63	47.7	15
16	11.31	100.39	94.6	10.57	87.83	77.4	16	9.844	76.11	62.4	9.11	65.23	49.5	16
17	11.44	102.71	97.9	10.7	89.90	80.2	17	9.962	77.94	64.7	9.23	66.84	51.4	17
18	11.57	105.05	101.2	10.82	91.99	83.0	18	10.08	79.80	67.0	9.34	68.47	53.3	18
19	11.69	107.42	104.7	10.95	94.11	85.8	19	10.2	81.68	69.4	9.45	70.12	55.2	19
20	11.82	109.82	108.2	11.07	96.25	88.8	20	10.32	83.58	71.8	9.56	71.80	57.2	20
21	11.95	112.24	111.8	11.19	98.41	91.8	21	10.43	85.50	74.3	9.67	73.49	59.2	21
22	12.08	114.69	115.5	11.32	100.60	94.9	22	10.55	87.44	76.9	9.79	75.20	61.3	22
23	12.21	117.16	119.2	11.44	102.81	98.0	23	10.67	89.40	79.5	9.90	76.93	63.4	23
24	12.34	119.66	123.1	11.57	105.05	101.2	24	10.79	91.39	82.2	10.01	78.68	65.6	24
25	12.47	122.19	127.0	11.69	107.31	104.5	25	10.91	93.40	84.9	10.12	80.45	67.9	25
26	12.6	124.74	131.0	11.81	109.60	107.9	26	11.02	95.43	87.7	10.23	82.24	70.1	26
27	12.73	127.32	135.1	11.94	111.91	111.3	27	11.14	97.48	90.5	10.35	84.05	72.5	27
28	12.86	129.93	139.3	12.06	114.24	114.8	28	11.26	99.56	93.4	10.46	85.88	74.8	28
29	12.99	132.56	143.5	12.18	116.60	118.4	29	11.38	101.65	96.4	10.57	87.73	77.3	29
30	13.12	135.22	147.9	12.31	118.98	122.0	30	11.49	103.77	99.4	10.68	89.60	79.8	30
31	13.25	137.91	152.3	12.43	121.38	125.7	31	11.61	105.91	102.5	10.79	91.49	82.3	31
32	13.38	140.62	156.8	12.56	123.81	129.5	32	11.73	108.07	105.6	10.91	93.40	84.9	32
33	13.51	143.36	161.4	12.68	126.27	133.4	33	11.85	110.25	108.9	11.02	95.33	87.5	33
34	13.64	146.13	166.1	12.8	128.74	137.4	34	11.97	112.46	112.1	11.13	97.28	90.2	34
35	13.77	148.92	170.9	12.93	131.24	141.4	35	12.08	114.69	115.5	11.24	99.24	93.0	35
36	13.9	151.74	175.8	13.05	133.77	145.5	36	12.2	116.93	118.9	11.35	101.23	95.8	36
37	14.03	154.58	180.7	13.17	136.32	149.7	37	12.32	119.21	122.4	11.47	103.24	98.6	37
38	14.16	157.45	185.8	13.3	138.89	153.9	38	12.44	121.50	125.9	11.58	105.27	101.6	38
39	14.29	160.35	190.9	13.42	141.49	158.3	39	12.56	123.81	129.5	11.69	107.31	104.5	39
40	14.42	163.27	196.2	13.55	144.11	162.7	40	12.67	126.15	133.2	11.80	109.38	107.6	40
41	14.55	166.22	201.5	13.67	146.76	167.2	41	12.79	126.51	137.0	11.91	111.46	110.7	41
42	14.68	169.20	207.0	13.79	149.43	171.8	42	12.91	130.89	140.8	12.03	113.57	113.8	42
43	14.81	172.20	212.5	13.92	152.12	176.4	43	13.03	133.29	144.7	12.14	115.70	117.0	43
44	14.94	175.23	218.1	14.04	154.84	181.2	44	13.15	135.71	148.7	12.25	117.84	120.3	44
45	15.07	178.29	223.9	14.16	157.58	186.0	45	13.26	138.16	152.7	12.36	120.01	123.6	45
46	15.2	181.37	229.7	14.29	160.35	190.9	46	13.38	140.62	156.8	12.47	122.19	127.0	46
47	15.33	184.48	235.6	14.41	163.14	195.9	47	13.5	143.11	161.0	12.59	124.39	130.5	47
48	15.46	187.62	241.6	14.54	165.95	201.0	48	13.62	145.62	165.2	12.70	126.62	134.0	48
49	15.59	190.78	247.8	14.66	168.79	206.2	49	13.73	148.15	169.6	12.81	128.86	137.5	49
50	15.72	193.96	254.0	14.78	171.66	211.5	50	13.85	150.71	174.0	12.92	131.12	141.2	50
51	15.84	197.18	260.4	14.91	174.54	216.8	51	13.97	153.28	178.5	13.03	133.41	144.9	51
52	15.97	200.42	266.8	15.03	177.45	222.3	52	14.09	155.88	183.0	13.15	135.71	148.7	52
53	16.1	203.69	273.4	15.16	180.39	227.8	53	14.21	158.50	187.6	13.26	138.03	152.5	53
54	16.23	206.98	280.0	15.28	183.35	233.4	54	14.32	161.14	192.4	13.37	140.37	156.4	54
55	16.3	208.69	283.5	15.35	184.95	236.5	55	14.39	162.65	195.1	13.44	141.78	158.7	55

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

60 ft. 60 ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
56	16.37	210.40	287.0	15.41	186.57	239.6	56	14.46	164.17	197.8	13.50	143.20	161.1	56
57	16.43	212.13	290.5	15.48	188.19	242.8	57	14.52	165.69	200.5	13.57	144.62	163.5	57
58	16.5	213.86	294.1	15.55	189.82	245.9	58	14.59	167.22	203.3	13.64	146.05	166.0	58
59	16.57	215.59	297.7	15.61	191.46	249.1	59	14.66	168.75	206.1	13.70	147.48	168.4	59
60	16.63	217.33	301.3	15.68	193.10	252.3	60	14.73	170.29	209.0	13.77	148.92	170.9	60

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

65 ft. 65 ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
0	9.23	66.9	51.5	8.59	58.0	41.5	0	7.96	49.7	33.0	7.32	42.1	25.7	0
1	9.36	68.8	53.6	8.72	59.7	43.3	1	8.07	51.2	34.4	7.43	43.4	26.9	1
2	9.48	70.7	55.8	8.84	61.3	45.2	2	8.19	52.7	36.0	7.54	44.7	28.1	2
3	9.61	72.6	58.1	8.96	63.0	47.1	3	8.31	54.2	37.5	7.65	46.0	29.3	3
4	9.74	74.5	60.4	9.08	64.8	49.0	4	8.42	55.7	39.1	7.76	47.3	30.6	4
5	9.86	76.4	62.8	9.20	66.5	51.0	5	8.54	57.2	40.7	7.87	48.7	32.0	5
6	9.99	78.4	65.3	9.32	68.3	53.0	6	8.65	58.8	42.4	7.98	50.1	33.3	6
7	10.12	80.4	67.8	9.44	70.1	55.1	7	8.77	60.4	44.1	8.10	51.5	34.7	7
8	10.25	82.4	70.4	9.57	71.9	57.3	8	8.89	62.0	45.9	8.21	52.9	36.2	8
9	10.37	84.5	73.0	9.69	73.7	59.5	9	9.00	63.6	47.7	8.32	54.3	37.6	9
10	10.50	86.6	75.7	9.81	75.6	61.8	10	9.12	65.3	49.6	8.43	55.8	39.2	10
11	10.63	88.7	78.5	9.93	77.4	64.1	11	9.23	67.0	51.5	8.54	57.2	40.7	11
12	10.75	90.8	81.4	10.05	79.3	66.5	12	9.35	68.7	53.5	8.65	58.7	42.3	12
13	10.88	93.0	84.3	10.17	81.3	68.9	13	9.47	70.4	55.5	8.76	60.3	44.0	13
14	11.01	95.1	87.3	10.29	83.2	71.4	14	9.58	72.1	57.6	8.87	61.8	45.7	14
15	11.13	97.3	90.3	10.42	85.2	73.9	15	9.70	73.9	59.7	8.98	63.3	47.4	15
16	11.26	99.6	93.4	10.54	87.2	76.6	16	9.81	75.6	61.9	9.09	64.9	49.2	16
17	11.39	101.8	96.6	10.66	89.2	79.2	17	9.93	77.4	64.1	9.20	66.5	51.0	17
18	11.51	104.1	99.9	10.78	91.3	82.0	18	10.05	79.3	66.4	9.31	68.1	52.8	18
19	11.64	106.4	103.2	10.90	93.3	84.8	19	10.16	81.1	68.7	9.42	69.7	54.8	19
20	11.77	108.7	106.6	11.02	95.4	87.6	20	10.28	83.0	71.1	9.53	71.4	56.7	20
21	11.89	111.1	110.1	11.14	97.5	90.6	21	10.39	84.8	73.5	9.64	73.0	58.7	21
22	12.02	113.5	113.7	11.26	99.7	93.6	22	10.51	86.7	76.0	9.75	74.7	60.7	22
23	12.15	115.9	117.3	11.39	101.8	96.6	23	10.63	88.7	78.5	9.86	76.4	62.8	23
24	12.27	118.3	121.0	11.51	104.0	99.7	24	10.74	90.6	81.1	9.98	78.2	65.0	24
25	12.40	120.8	124.8	11.63	106.2	102.9	25	10.86	92.6	83.5	10.09	79.9	67.2	25
26	12.53	123.3	128.7	11.75	108.4	106.2	26	10.97	94.6	86.5	10.20	81.7	69.4	26
27	12.65	125.8	132.6	11.87	110.7	109.5	27	11.09	96.6	89.3	10.31	83.4	71.7	27
28	12.78	128.3	136.6	11.99	113.0	112.9	28	11.21	98.6	92.1	10.42	85.2	74.0	28
29	12.91	130.9	140.8	12.11	115.3	116.4	29	11.32	100.7	95.0	10.53	87.1	76.4	29
30	13.03	133.4	144.9	12.24	117.6	119.9	30	11.44	102.7	97.9	10.64	88.9	78.8	30
31	13.16	136.0	149.2	12.36	119.9	123.5	31	11.55	104.8	100.9	10.75	90.8	81.3	31
32	13.29	138.7	153.6	12.48	122.3	127.2	32	11.67	107.0	104.0	10.86	92.6	83.8	32
33	13.41	141.3	158.0	12.60	124.7	130.9	33	11.79	109.1	107.1	10.97	94.5	86.4	33
34	13.54	144.0	162.5	12.72	127.1	134.8	34	11.90	111.2	110.3	11.08	96.4	89.1	34
35	13.67	146.7	167.1	12.84	129.5	138.6	35	12.02	113.4	113.6	11.19	98.4	91.8	35
36	13.80	149.5	171.8	12.96	132.0	142.6	36	12.13	115.6	116.9	11.30	100.3	94.5	36
37	13.92	152.2	176.6	13.09	134.5	146.7	37	12.25	117.8	120.3	11.41	102.3	97.3	37
38	14.05	155.0	181.5	13.21	137.0	150.8	38	12.37	120.1	123.8	11.52	104.3	100.2	38
39	14.18	157.8	186.4	13.33	139.5	155.0	39	12.48	122.4	127.3	11.63	106.3	103.1	39
40	14.30	160.7	191.5	13.45	142.1	159.2	40	12.60	124.6	130.8	11.75	108.3	106.0	40
41	14.43	163.5	196.6	13.57	144.7	163.6	41	12.71	126.9	134.5	11.86	110.4	109.1	41
42	14.56	166.4	201.9	13.69	147.3	168.0	42	12.83	129.3	138.2	11.97	112.5	112.1	42
43	14.68	169.3	207.2	13.81	149.9	172.5	43	12.95	131.6	142.0	12.08	114.6	115.3	43
44	14.81	172.3	212.6	13.94	152.5	177.1	44	13.06	134.0	145.8	12.19	116.7	118.5	44
45	14.94	175.2	218.1	14.06	155.2	181.8	45	13.18	136.4	149.8	12.30	118.8	121.7	45
46	15.06	178.2	223.7	14.18	157.9	186.5	46	13.29	138.8	153.8	12.41	120.9	125.1	46
47	15.19	181.2	229.4	14.30	160.6	191.4	47	13.41	141.2	157.8	12.52	123.1	128.4	47
48	15.32	184.3	235.2	14.42	163.3	196.3	48	13.53	143.7	161.9	12.63	125.3	131.9	48
49	15.44	187.3	241.1	14.54	166.1	201.3	49	13.64	146.2	166.1	12.74	127.5	135.4	49
50	15.57	190.4	247.1	14.66	168.9	206.4	50	13.76	148.7	170.4	12.85	129.7	138.9	50
51	15.70	193.5	253.1	14.79	171.7	211.5	51	13.87	151.2	174.8	12.96	132.0	142.5	51
52	15.82	196.7	259.3	14.91	174.5	216.8	52	13.99	153.7	179.2	13.07	134.2	146.2	52
53	15.95	199.8	265.6	15.03	177.4	222.1	53	14.11	156.3	183.7	13.18	136.5	149.9	53
54	16.08	203.0	272.0	15.15	180.3	227.6	54	14.22	158.8	188.3	13.29	138.8	153.8	54
55	16.20	206.2	278.5	15.27	183.2	233.1	55	14.34	161.4	192.9	13.40	141.1	157.6	55

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

65 ft. 65 ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
56	16.33	209.5	285.1	15.39	186.1	238.7	56	14.45	164.1	197.6	13.51	143.5	161.6	56
57	16.46	212.7	291.8	15.51	189.0	244.4	57	14.57	166.7	202.4	13.63	145.8	165.6	57
58	16.58	216.0	298.5	15.63	192.0	250.1	58	14.69	169.4	207.3	13.74	148.2	169.6	58
59	16.71	219.3	305.4	15.76	195.0	256.0	59	14.80	172.1	212.2	13.85	150.6	173.8	59
60	16.78	221.1	309.1	15.82	196.6	259.3	60	14.87	173.6	215.1	13.91	152.0	176.3	60
61	16.84	222.9	312.8	15.89	198.3	262.6	61	14.94	175.2	218.0	13.98	153.5	178.8	61
62	16.91	224.6	316.6	15.96	200.0	265.9	62	15.00	176.8	221.0	14.05	155.0	181.4	62
63	16.98	226.4	320.3	16.02	201.7	269.3	63	15.07	178.3	223.9	14.11	156.5	184.0	63
64	17.05	228.2	324.1	16.09	203.3	272.7	64	15.14	179.9	226.9	14.18	157.9	186.6	64
65	17.11	230.0	328.0	16.16	205.0	276.1	65	15.20	181.5	230.0	14.25	159.4	189.3	65

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

70 ft. 70 ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
0	9.23	66.9	51.5	8.59	58.0	41.5	0	7.96	49.7	33.0	7.32	42.1	25.7	0
1	9.36	68.7	53.6	8.71	59.6	43.3	1	8.07	51.2	34.4	7.43	43.4	26.9	1
2	9.48	70.6	55.8	8.83	61.3	45.1	2	8.19	52.6	35.9	7.54	44.7	28.1	2
3	9.60	72.4	58.0	8.95	62.8	47.0	3	8.30	54.1	37.4	7.65	46.0	29.3	3
4	9.73	74.3	60.3	9.07	64.6	48.9	4	8.42	55.6	39.0	7.76	47.3	30.6	4
5	9.85	76.2	62.6	9.19	66.3	50.8	5	8.53	57.1	40.6	7.87	48.6	31.9	5
6	9.98	78.2	65.0	9.31	68.1	52.8	6	8.64	58.7	42.3	7.98	50.0	33.2	6
7	10.10	80.1	67.5	9.43	69.8	54.9	7	8.76	60.2	44.0	8.09	51.4	34.6	7
8	10.23	82.1	70.0	9.55	71.6	57.0	8	8.87	61.8	45.7	8.20	52.8	36.0	8
9	10.35	84.1	72.6	9.67	73.4	59.2	9	8.99	63.4	47.5	8.31	54.2	37.2	9
10	10.47	86.2	75.2	9.79	75.2	61.4	10	9.10	65.1	49.3	8.42	55.6	39.0	10
11	10.60	88.2	77.9	9.91	77.1	63.6	11	9.22	66.7	51.2	8.52	57.1	40.5	11
12	10.72	90.3	80.7	10.03	79.0	66.0	12	9.33	68.4	53.2	8.63	58.6	42.1	12
13	10.85	92.4	83.5	10.15	80.9	68.4	13	9.44	70.1	55.1	8.74	60.0	43.7	13
14	10.97	94.5	86.4	10.27	82.8	70.8	14	9.56	71.8	57.2	8.85	61.6	45.4	14
15	11.10	96.7	89.4	10.38	84.7	73.3	15	9.67	73.5	59.2	8.96	63.1	47.1	15
16	11.22	98.9	92.5	10.50	86.7	75.9	16	9.79	75.2	61.4	9.07	64.2	48.9	16
17	11.34	101.1	95.6	10.62	88.6	78.5	17	9.90	77.0	63.6	9.18	66.2	50.7	17
18	11.47	103.3	98.7	10.74	90.6	81.1	18	10.02	78.8	65.8	9.29	67.8	52.5	18
19	11.59	105.6	102.0	10.86	92.7	83.9	19	10.13	80.6	68.1	9.40	69.4	54.4	19
20	11.72	107.8	105.3	10.98	94.7	86.7	20	10.25	82.4	70.4	9.51	71.0	56.3	20
21	11.84	110.1	108.7	11.10	96.8	89.5	21	10.36	84.3	72.8	9.62	72.7	58.2	21
22	11.97	112.5	112.2	11.22	98.9	92.5	22	10.47	86.2	75.2	9.73	74.3	60.3	22
23	12.09	114.8	115.7	11.34	101.0	94.5	23	10.59	88.1	77.7	9.84	76.0	62.3	23
24	12.22	117.2	119.3	11.46	103.1	98.5	24	10.70	90.0	80.3	9.95	77.7	64.4	24
25	12.34	119.6	123.0	11.58	105.3	101.6	25	10.82	91.9	82.9	10.06	79.4	66.6	25
26	12.46	122.0	126.7	11.70	107.5	104.8	26	10.93	93.9	85.5	10.17	81.2	68.8	26
27	12.59	124.5	130.6	11.82	109.7	108.8	27	11.05	95.8	88.2	10.28	82.9	71.0	27
28	12.71	126.9	134.5	11.94	111.9	111.3	28	11.16	97.8	91.0	10.38	84.7	73.3	28
29	12.84	129.4	138.4	12.06	114.2	114.7	29	11.28	99.8	93.8	10.49	86.5	75.6	29
30	12.96	131.9	142.5	12.18	116.4	118.1	30	11.39	101.9	96.7	10.60	88.3	78.0	30
31	13.09	134.5	146.6	12.29	118.7	121.6	31	11.50	103.9	99.6	10.71	90.1	80.5	31
32	13.21	137.1	150.9	12.41	121.0	125.2	32	11.62	106.9	102.6	10.82	92.0	83.0	32
33	13.33	139.6	155.2	12.53	123.4	128.9	33	11.73	108.1	105.7	10.93	93.9	85.5	33
34	13.46	142.3	159.6	12.65	125.7	132.6	34	11.85	110.2	108.8	11.04	95.7	88.1	34
35	13.58	144.9	164.0	12.77	128.1	136.4	35	11.96	112.4	112.0	11.15	97.7	90.7	35
36	13.71	147.6	168.6	12.89	130.5	140.2	36	12.08	114.5	115.3	11.26	99.6	93.4	36
37	13.83	150.3	173.2	13.01	133.0	144.2	37	12.19	116.7	118.6	11.37	101.5	96.2	37
38	13.96	153.0	177.9	13.13	135.4	148.2	38	12.30	118.9	121.9	11.48	103.5	99.0	38
39	14.08	155.7	182.7	13.25	137.9	152.2	39	12.42	121.1	125.4	11.59	105.5	101.9	39
40	14.20	158.5	187.6	13.37	140.4	156.4	40	12.53	123.4	128.9	11.70	107.5	104.8	40
41	14.33	161.3	192.6	13.49	142.9	160.6	41	12.65	125.6	132.4	11.81	109.5	107.7	41
42	14.45	164.1	197.6	13.61	145.4	164.9	42	12.76	127.9	126.0	11.92	111.5	110.8	42
43	14.58	166.9	202.8	13.73	148.0	169.3	43	12.88	130.2	139.7	12.03	113.6	113.8	43
44	14.70	169.8	208.0	13.85	150.6	173.8	44	12.99	132.5	143.5	12.14	115.7	117.0	44
45	14.83	172.6	213.3	13.97	153.2	178.3	45	13.11	134.9	147.3	12.24	117.8	120.2	45
46	14.95	175.6	218.7	14.09	155.8	182.9	46	13.22	137.3	151.2	12.35	119.9	123.4	46
47	15.07	178.5	224.2	14.20	158.5	187.6	47	13.33	139.6	155.2	12.46	122.0	126.7	47
48	15.20	181.4	229.8	14.32	161.1	192.4	48	13.45	142.1	159.2	12.57	124.2	130.1	48
49	15.32	184.4	235.5	14.44	163.5	197.2	49	13.56	144.5	163.3	12.68	126.3	133.5	49
50	15.45	187.4	241.3	14.56	166.6	202.1	50	13.68	146.9	167.5	12.79	128.5	137.0	50
51	15.57	190.5	247.2	14.68	169.3	207.1	51	13.79	149.4	171.7	12.90	130.7	140.5	51
52	15.70	193.5	253.1	14.80	172.1	212.2	52	13.91	151.9	176.0	13.01	133.0	144.2	52
53	15.82	196.6	259.2	14.92	174.9	217.4	53	14.02	154.4	180.4	13.12	135.2	147.8	53
54	15.95	199.7	265.3	15.04	177.7	222.7	54	14.13	156.9	184.8	13.23	137.5	151.6	54
55	16.07	202.8	271.6	15.16	180.5	228.0	55	14.25	159.5	189.4	13.34	139.7	155.3	55

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

70 ft. 70 ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
56	16.19	206.0	278.0	15.28	183.3	233.4	56	14.36	162.0	194.0	13.45	142.1	159.2	56
57	16.32	209.1	284.4	15.40	186.2	239.0	57	14.48	164.6	198.6	13.56	144.4	163.1	57
58	16.44	212.3	291.0	15.52	189.1	244.6	58	14.59	167.2	203.4	13.67	146.7	167.1	58
59	16.57	215.6	297.6	15.64	192.0	250.2	59	14.71	169.9	208.2	13.78	149.1	171.1	59
60	16.69	218.8	304.4	15.76	195.0	256.0	60	14.82	172.5	213.1	13.89	151.4	175.3	60
61	16.82	222.1	311.2	15.88	198.0	261.9	61	14.94	175.2	218.1	14.00	153.8	179.4	61
62	16.94	225.4	318.2	16.00	200.9	267.8	62	15.05	177.9	223.1	14.11	156.3	183.7	62
63	17.06	228.7	325.2	16.11	203.9	273.9	63	15.16	180.6	228.2	14.21	158.7	188.0	63
64	17.19	232.0	332.4	16.23	207.9	280.0	64	15.28	183.3	233.4	14.32	161.1	192.4	64
65	17.26	233.9	336.3	16.30	208.9	283.5	65	15.35	185.0	236.5	14.39	162.7	195.1	65
66	17.32	235.7	340.2	16.37	210.4	287.0	66	15.41	186.6	239.6	14.46	164.2	197.8	66
67	17.39	237.5	344.2	16.43	212.1	290.5	67	15.48	188.2	242.8	14.52	165.7	200.5	67
68	17.46	239.3	348.1	16.50	213.9	294.1	68	15.55	189.8	245.9	14.59	167.2	203.3	68
69	17.52	241.2	352.2	16.57	215.6	297.7	69	15.61	191.5	249.1	14.66	168.8	206.1	69
70	17.59	243.0	356.2	16.63	217.3	301.3	70	15.68	193.1	252.3	14.73	170.3	209.0	70

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

75 ft. 75 ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
0	9.23	66.9	51.3	8.59	58.0	41.5	0	7.96	49.7	33.0	7.32	42.1	25.7	0
1	9.35	68.7	53.6	8.71	59.6	43.3	1	8.07	51.1	34.4	7.43	43.3	26.8	1
2	9.48	70.5	55.7	8.83	61.2	45.1	2	8.18	52.5	35.8	7.53	44.6	28.0	2
3	9.60	72.3	57.9	8.95	62.9	46.9	3	8.29	54.0	37.3	7.64	45.8	29.2	3
4	9.72	74.2	60.1	9.06	64.5	48.8	4	8.40	55.4	38.8	7.75	47.1	30.4	4
5	9.84	76.1	62.4	9.18	66.2	50.7	5	8.51	56.9	40.4	7.85	48.4	31.7	5
6	9.96	78.0	64.8	9.30	67.9	52.6	6	8.62	58.4	42.0	7.96	49.7	33.0	6
7	10.09	79.9	67.2	9.42	69.7	54.7	7	8.73	59.9	43.6	8.06	51.1	34.3	7
8	10.21	81.9	69.6	9.54	71.4	56.7	8	8.84	61.4	45.3	8.17	52.4	35.7	8
9	10.33	83.8	72.2	9.65	73.2	58.9	9	8.95	63.0	47.0	8.28	53.8	37.1	9
10	10.45	85.8	74.8	9.77	75.0	61.1	10	9.06	64.5	48.8	8.38	55.2	38.5	10
11	10.58	87.8	77.4	9.89	76.8	63.3	11	9.18	66.1	50.6	8.49	56.6	40.0	11
12	10.70	89.9	80.1	10.01	78.6	65.6	12	9.29	67.7	52.4	8.59	58.0	41.5	12
13	10.82	92.0	82.9	10.12	80.5	67.9	13	9.40	69.4	54.3	8.70	59.5	43.1	13
14	10.94	94.0	85.8	10.24	82.4	70.3	14	9.51	71.0	56.3	8.81	60.9	44.7	14
15	11.06	96.2	88.7	10.36	84.3	72.8	15	9.62	72.7	58.2	8.91	62.4	46.3	15
16	11.19	98.3	91.6	10.48	86.2	73.5	16	9.73	74.3	60.3	9.02	63.9	48.0	16
17	11.31	100.5	94.7	10.59	88.2	77.8	17	9.84	76.0	62.4	9.12	65.4	49.7	17
18	11.43	102.6	97.8	10.71	90.1	80.4	18	9.95	77.8	64.5	9.23	66.9	51.5	18
19	11.55	104.8	100.9	10.83	92.1	83.1	19	10.06	79.5	66.7	9.34	68.5	53.3	19
20	11.68	107.1	104.2	10.95	94.1	85.9	20	10.17	81.3	68.9	9.44	70.0	55.1	20
21	11.80	109.3	107.5	11.06	96.2	88.7	21	10.28	83.0	71.2	9.55	71.6	57.0	21
22	11.92	111.6	110.9	11.18	98.2	91.5	22	10.39	84.8	73.8	9.66	73.2	58.9	22
23	12.04	113.9	114.3	11.30	100.3	94.4	23	10.50	86.7	75.9	9.76	74.8	60.9	23
24	12.16	116.2	117.8	11.42	102.4	97.4	24	10.61	88.5	78.3	9.87	76.5	62.9	24
25	12.29	118.6	121.4	11.54	104.5	100.5	25	10.73	90.4	80.8	9.97	78.1	64.9	25
26	12.41	120.9	125.1	11.65	106.6	103.6	26	10.84	92.2	83.3	10.08	79.8	67.0	26
27	12.53	123.3	128.8	11.77	108.8	106.7	27	10.95	94.1	85.9	10.19	81.5	69.2	27
28	12.65	125.8	132.6	11.89	111.0	110.0	28	11.06	96.0	88.5	10.29	83.2	71.4	28
29	12.78	128.2	136.5	12.01	113.2	113.3	29	11.17	98.0	91.2	10.40	84.9	73.6	29
30	12.90	130.7	140.5	12.12	115.4	116.6	30	11.28	99.9	93.9	10.50	86.7	75.9	30
31	13.02	133.2	144.5	12.24	117.7	120.1	31	11.39	101.9	96.7	10.61	88.4	78.2	31
32	13.14	135.7	148.6	12.36	120.0	123.5	32	11.50	103.9	99.6	10.72	90.2	80.5	32
33	13.27	138.2	152.8	12.48	122.3	127.1	33	11.61	105.9	102.5	10.82	92.0	83.0	33
34	13.39	140.8	157.0	12.59	124.6	130.7	34	11.72	107.9	105.4	10.93	93.8	85.4	34
35	13.51	143.3	161.4	12.71	126.9	134.4	35	11.83	110.0	108.4	11.03	95.6	87.9	35
36	13.63	146.0	165.8	12.83	129.3	138.2	36	11.94	112.0	111.5	11.14	97.5	90.5	36
37	13.75	148.6	170.3	12.95	131.7	142.0	37	12.05	114.1	114.6	11.25	99.3	93.1	37
38	13.88	151.2	174.9	13.06	134.1	145.9	38	12.16	116.2	117.8	11.35	101.2	95.8	38
39	14.00	153.9	179.5	13.18	136.5	149.9	39	12.28	118.4	121.1	11.46	103.1	98.5	39
40	14.12	156.6	184.3	13.30	138.9	154.0	40	12.39	120.5	124.4	11.57	105.1	101.2	40
41	14.24	159.3	189.1	13.42	141.4	158.1	41	12.50	122.7	127.7	11.67	107.0	104.1	41
42	14.37	162.1	194.0	13.54	143.9	162.3	42	12.61	124.8	131.2	11.78	108.9	106.9	42
43	14.49	164.9	199.0	13.65	146.4	166.6	43	12.72	127.0	134.7	11.88	110.9	109.8	43
44	14.61	167.6	204.1	13.77	148.9	170.9	44	12.83	129.3	138.2	11.99	112.9	112.8	44
45	14.73	170.5	209.3	13.89	151.5	175.3	45	12.94	131.5	141.8	12.10	114.9	115.8	45
46	14.85	173.3	214.5	14.01	154.1	179.8	46	13.05	133.8	145.5	12.20	116.9	118.9	46
47	14.98	176.2	219.9	14.12	156.7	184.4	47	13.16	136.0	149.2	12.31	119.0	122.0	47
48	15.10	179.1	225.3	14.24	159.3	189.0	48	13.27	138.3	153.0	12.41	121.0	125.2	48
49	15.22	182.0	230.8	14.36	161.9	193.7	49	13.38	140.7	156.9	12.52	123.1	128.5	49
50	15.34	184.9	236.4	14.48	164.6	198.6	50	13.49	143.0	160.8	12.62	125.2	131.7	50
51	15.47	187.9	242.1	14.59	167.3	203.4	51	13.60	145.4	164.8	12.73	127.3	135.1	51
52	15.59	190.8	247.9	14.71	170.0	208.4	52	13.72	147.7	168.8	12.84	129.5	138.5	52
53	15.71	193.8	253.8	14.83	172.7	213.4	53	13.83	150.1	173.0	12.94	131.6	142.0	53
54	15.83	196.9	259.7	14.95	175.5	218.5	54	13.94	152.5	177.2	13.05	133.8	145.5	54
55	15.95	199.9	265.8	15.06	178.2	223.7	55	14.05	155.0	181.4	13.16	136.0	149.1	55

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

75 ft. 75ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
56	16.08	203.0	272.0	15.18	181.0	229.0	56	14.16	157.4	185.7	13.26	138.2	152.7	56
57	16.20	206.1	278.2	15.30	183.8	234.4	57	14.27	159.9	190.1	13.37	140.4	156.4	57
58	16.32	209.2	284.6	15.42	186.7	239.8	58	14.38	162.4	194.6	13.48	142.6	160.1	58
59	16.44	212.4	291.0	15.53	189.5	245.4	59	14.49	164.9	199.1	13.58	144.9	164.0	59
60	16.57	215.5	297.5	15.65	192.4	251.0	60	14.60	167.4	203.7	13.69	147.1	167.8	60
61	16.69	218.7	304.2	15.77	195.3	256.7	61	14.71	170.0	208.4	13.79	149.4	171.8	61
62	16.81	221.9	310.9	15.89	198.3	262.5	62	14.82	172.5	213.1	13.90	151.7	175.8	62
63	16.93	225.2	317.8	16.01	201.2	268.4	63	14.93	175.1	217.9	14.01	154.1	179.8	63
64	17.05	228.4	324.7	16.12	204.2	274.3	64	15.04	177.7	222.8	14.11	156.4	183.9	64
65	17.18	231.7	331.17	16.24	207.2	280.4	65	15.15	180.4	227.8	14.22	158.8	188.1	65
66	17.30	235.0	338.8	16.36	210.2	286.5	66	15.27	183.0	232.8	14.32	161.1	192.4	66
67	17.42	238.4	346.1	16.48	213.2	292.7	67	15.38	185.7	237.9	14.43	163.5	196.7	67
68	17.54	241.7	353.4	16.59	216.3	299.0	68	15.49	188.4	243.1	14.54	166.0	201.0	68
69	17.67	245.1	360.9	16.71	219.3	305.4	69	15.60	191.1	248.3	14.64	168.4	205.5	69
70	17.73	247.0	365.0	16.78	221.1	309.1	70	15.66	192.7	251.5	14.71	169.9	208.3	70
71	17.80	248.8	369.1	16.84	222.9	312.8	71	15.73	194.4	254.8	14.78	171.5	211.1	71
72	17.87	250.7	373.3	16.91	224.6	316.6	72	15.80	196.0	258.0	14.84	173.0	214.0	72
73	17.93	252.6	377.5	16.98	226.4	320.3	73	15.86	197.7	261.3	14.91	174.6	216.9	73
74	18.00	254.5	381.7	17.05	228.2	324.1	74	15.93	199.3	264.6	14.98	176.2	219.9	74
75	18.07	256.4	386.0	17.11	230.0	328.0	75	16.00	201.0	268.0	15.04	177.7	222.8	75

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

80 ft. 80 ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
0	9.231	66.92	51.5	8.594	58.01	41.5	0	7.958	49.74	33.0	7.321	42.10	25.7	0
1	9.351	66.68	53.5	8.711	59.59	43.3	1	8.067	51.12	34.4	7.424	43.29	26.8	1
2	9.472	70.46	55.6	8.827	61.19	45.0	2	8.177	52.52	35.8	7.528	44.50	27.9	2
3	9.592	72.27	57.8	8.943	62.81	46.8	3	8.287	53.93	37.2	7.631	45.73	29.1	3
4	9.713	74.09	60.0	9.059	64.45	48.7	4	8.396	55.37	38.7	7.734	46.98	30.3	4
5	9.833	75.94	62.2	9.175	66.12	50.6	5	8.506	56.83	40.3	7.837	48.24	31.5	5
6	9.954	77.81	64.5	9.291	67.80	52.5	6	8.616	58.30	41.9	7.941	49.52	32.8	6
7	10.07	79.71	66.9	9.407	69.51	54.5	7	8.726	59.80	43.5	8.044	50.82	34.1	7
8	10.19	81.63	69.3	9.523	71.23	56.5	8	8.835	61.31	45.1	8.147	52.13	35.4	8
9	10.31	83.57	71.8	9.64	72.98	58.6	9	8.945	62.84	46.8	8.25	53.46	36.8	9
10	10.44	85.53	74.4	9.756	74.75	60.8	10	9.055	64.39	48.6	8.353	54.81	38.2	10
11	10.56	87.51	77.0	9.872	76.54	63.0	11	9.164	65.96	50.46	8.457	56.17	39.6	11
12	10.68	89.52	79.6	9.988	78.35	65.2	12	9.274	67.55	52.2	8.56	57.55	41.1	12
13	10.8	91.55	82.4	10.1	80.18	67.5	13	9.384	69.16	54.1	8.663	58.94	42.6	13
14	10.92	93.61	85.2	10.22	82.04	69.9	14	9.493	70.78	56.0	8.766	60.36	44.1	14
15	11.04	95.68	88.0	10.34	83.91	72.3	15	9.603	72.43	58.0	8.87	61.79	45.7	15
16	11.16	97.78	90.9	10.45	85.81	74.7	16	9.713	74.09	60.0	8.973	63.23	47.3	16
17	11.28	99.91	93.9	10.57	87.73	77.3	17	9.822	75.78	62.0	9.076	64.70	48.9	17
18	11.4	102.05	96.9	10.68	89.67	79.8	18	9.932	77.48	64.1	9.179	66.18	50.6	18
19	11.52	104.22	100.0	10.8	91.63	82.5	19	10.04	79.20	66.3	9.283	67.68	52.4	19
20	11.64	106.41	103.2	10.92	93.61	85.2	20	10.15	80.94	68.5	9.386	69.19	54.1	20
21	11.76	108.62	106.5	11.03	95.61	87.9	21	10.26	82.70	70.7	9.489	70.72	55.9	21
22	11.88	110.86	109.8	11.15	97.63	90.7	22	10.37	84.47	73.0	9.592	72.27	57.8	22
23	12	113.12	113.1	11.27	99.68	93.6	23	10.48	86.27	75.3	9.696	73.83	59.7	23
24	12.12	115.40	116.6	11.38	101.74	96.5	24	10.59	88.09	77.7	9.799	75.41	61.6	24
25	12.24	117.71	120.1	11.5	103.83	99.5	25	10.7	89.92	80.2	9.902	77.01	63.5	25
26	12.36	120.03	123.7	11.61	105.94	102.5	26	10.81	91.77	82.7	10.01	78.62	65.6	26
27	12.48	122.38	127.3	11.73	108.07	105.6	27		93.64	85.2	10.11	80.25	67.6	27
28	12.6	124.76	131.0	11.85	110.22	108.8	28		95.54	87.8	10.21	81.90	69.7	28
29	12.72	127.15	134.8	11.96	112.39	112.0	29		97.44	90.5	10.31	83.57	71.8	29
30	12.84	129.57	138.7	12.08	114.58	115.3	30		99.37	93.1	10.42	85.25	74.0	30
31	12.96	132.01	142.6	12.19	116.80	118.7	31		101.32	95.9	10.52	86.94	76.2	31
32	13.09	134.48	146.6	12.31	119.03	122.1	32		103.29	98.7	10.62	88.66	78.5	32
33	13.21	136.96	150.7	12.43	121.29	125.6	33		105.27	101.6	10.73	90.39	80.8	33
34	13.33	139.47	154.9	12.54	123.57	129.2	34		107.28	104.5	10.83	92.14	83.2	34
35	13.45	142.01	159.1	12.66	125.87	132.8	35		109.30	107.4	10.93	93.90	85.6	35
36	13.57	144.56	163.4	12.78	128.19	136.5	36		111.34	110.5	11.04	95.68	88.0	36
37	13.69	147.14	167.8	12.89	130.53	140.2	37		113.40	113.6	11.14	97.48	90.5	37
38	13.81	149.74	172.3	13.01	132.89	144.0	38		115.48	116.7	11.24	99.30	93.0	38
39	13.93	152.36	176.8	13.12	135.27	147.9	39		117.58	119.9	11.35	101.13	95.6	39
40	14.05	155.01	181.5	13.24	137.68	151.9	40		119.70	123.1	11.45	102.98	98.3	40
41	14.17	157.68	186.2	13.36	140.10	155.9	41		121.84	126.5	11.55	104.84	100.9	41
42	14.29	160.37	191.0	13.47	142.55	160.0	42		123.99	129.8	11.66	106.72	103.7	42
43	14.41	163.09	195.8	13.59	145.02	164.2	43		126.17	133.3	11.76	108.62	106.5	43
44	14.53	165.82	200.8	13.7	147.51	168.5	44		128.36	136.7	11.86	110.54	109.3	44
45	14.65	168.58	205.8	13.82	150.02	172.8	45		130.57	140.3	11.97	112.47	112.2	45
46	14.77	171.37	210.9	13.94	152.55	177.2	46		132.80	143.9	12.07	114.42	115.1	46
47	14.89	174.17	216.1	14.05	155.10	181.6	47		135.05	147.6	12.17	116.39	118.1	47
48	15.01	177.00	221.4	14.17	157.68	186.2	48		137.32	151.3	12.28	118.37	121.1	48
49	15.13	179.85	226.8	14.29	160.27	190.8	49		139.61	155.1	12.38	120.37	124.2	49
50	15.25	182.73	232.3	14.4	162.89	195.5	50		141.91	159.0	12.48	122.38	127.3	50
51	15.37	185.62	237.8	14.52	165.53	200.3	51		144.24	162.9	12.59	124.42	130.5	51
52	15.49	188.54	243.4	14.63	168.19	205.1	52		146.58	166.9	12.69	126.47	133.7	52
53	15.61	191.49	249.2	14.75	170.87	210.0	53		148.95	170.9	12.79	128.53	137.0	53
54	15.73	194.45	255.0	14.87	173.57	215.0	54		151.33	175.0	12.9	130.61	140.4	54
55	15.86	197.44	260.9	14.98	176.29	220.1	55		153.73	179.2	13	132.71	143.8	55

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

80 ft. 80 ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
56	15.98	200.45	266.9	15.1	179.04	225.3	56	14.1	156.15	183.5	13.1	134.83	147.2	56
57	16.1	203.49	272.9	15.21	181.80	230.5	57	14.21	158.59	187.8	13.21	136.96	150.7	57
58	16.22	206.54	279.1	15.33	184.59	235.8	58	14.32	161.05	192.2	13.31	139.11	154.3	58
59	16.34	209.62	285.4	15.45	187.39	241.2	59	14.43	163.52	196.6	13.41	141.28	157.9	59
60	16.46	212.72	291.7	15.56	190.22	246.7	60	14.54	166.02	201.1	13.52	143.46	161.6	60
61	16.58	215.85	298.2	15.68	193.07	252.3	61	14.65	168.53	205.7	13.62	145.66	165.3	61
62	16.7	219.00	304.7	15.8	195.94	257.9	62	14.76	171.07	210.4	13.72	147.88	169.1	62
63	16.82	222.17	311.4	15.91	198.84	263.6	63	14.87	173.62	215.1	13.82	150.11	172.9	63
64	16.94	225.36	318.1	16.03	201.75	269.5	64	14.98	176.19	219.9	13.93	152.36	176.8	64
65	17.06	228.58	325.0	16.14	204.68	275.4	65	15.09	178.78	224.8	14.03	154.63	180.8	65
66	17.18	231.82	331.9	16.26	207.64	281.3	66	15.2	181.39	229.7	14.13	156.91	184.8	66
67	17.3	235.08	338.9	16.38	201.62	287.4	67	15.31	184.02	234.7	14.24	159.21	188.9	67
68	17.42	238.36	346.0	16.49	213.61	293.6	68	15.42	186.66	239.8	14.34	161.53	193.0	68
69	17.54	241.67	353.3	16.61	216.63	299.8	69	15.53	189.33	245.0	14.44	163.87	197.2	69
70	17.66	245.00	360.6	16.72	219.67	306.2	70	15.64	192.02	250.2	14.55	166.22	201.5	70
71	17.78	248.35	368.0	16.84	222.74	312.6	71	15.75	194.72	255.5	14.65	168.58	205.8	71
72	17.9	251.73	375.6	16.96	225.82	319.1	72	15.86	197.44	260.9	14.75	170.97	210.2	72
73	18.02	255.13	383.2	17.07	228.92	325.7	73	15.96	200.18	266.3	14.86	173.37	214.6	73
74	18.14	258.55	390.9	17.19	232.05	332.4	74	16.07	202.94	271.9	14.96	175.79	219.2	74
75	18.21	260.46	395.3	17.26	233.86	336.3	75	16.14	204.63	275.3	15.03	177.36	222.1	75
76	18.28	262.37	399.6	17.32	235.67	340.2	76	16.21	206.33	278.7	15.09	178.94	225.1	76
77	18.34	264.29	404.0	17.39	237.49	344.2	77	16.28	208.04	282.2	15.16	180.53	228.1	77
78	18.41	266.22	408.5	17.46	239.32	348.1	78	16.34	209.75	285.6	15.23	182.13	231.1	78
79	18.48	268.16	412.9	17.52	241.16	352.2	79	16.41	211.47	289.2	15.29	183.73	234.2	79
80	18.54	270.10	417.4	17.59	243.00	356.2	80	16.48	213.20	292.7	15.36	185.34	237.3	80

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

85 ft. 85 ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.35	68.66	53.5	8.71	59.55	43.2	1	8.06	51.08	34.3	7.42	43.26	26.8	1
2	9.47	70.42	55.6	8.82	61.10	44.9	2	8.17	52.44	35.7	7.52	44.45	27.9	2
3	9.59	72.20	57.7	8.93	62.67	46.7	3	8.28	53.82	37.1	7.62	45.64	29.0	3
4	9.71	74.00	59.9	9.05	64.26	48.4	4	8.38	55.22	38.6	7.72	46.86	30.2	4
5	9.83	75.82	62.1	9.16	65.88	50.3	5	8.49	56.63	40.1	7.82	48.09	31.4	5
6	9.94	77.67	64.4	9.27	67.51	52.2	6	8.60	58.07	41.6	7.93	49.33	32.6	6
7	10.06	79.53	66.7	9.38	69.16	54.1	7	8.71	59.52	43.2	8.03	50.60	33.8	7
8	10.18	81.42	69.1	9.50	70.84	56.1	8	8.81	60.99	44.8	8.13	51.87	35.1	8
9	10.30	83.34	71.5	9.61	72.53	58.1	9	8.92	62.47	46.4	8.23	53.17	36.5	9
10	10.42	85.27	74.0	9.72	74.24	60.2	10	9.03	63.98	48.1	8.33	54.48	37.8	10
11	10.54	87.23	76.6	9.84	75.98	62.3	11	9.13	65.50	49.8	8.43	55.80	39.2	11
12	10.66	89.20	79.2	9.95	77.73	64.4	12	9.24	67.04	51.6	8.53	57.14	40.6	12
13	10.78	91.21	81.9	10.06	79.50	66.7	13	9.35	68.60	53.4	8.63	58.50	42.1	13
14	10.90	93.23	84.6	10.17	81.29	68.9	14	9.45	70.18	55.3	8.73	59.88	43.6	14
15	11.01	95.27	87.4	10.29	83.11	71.2	15	9.56	71.77	57.2	8.83	61.27	45.1	15
16	11.13	97.34	90.3	10.40	84.94	73.6	16	9.67	73.38	59.1	8.93	62.67	46.7	16
17	11.25	99.43	93.2	10.51	86.79	76.0	17	9.77	75.01	61.1	9.03	64.09	48.2	17
18	11.37	101.54	96.2	10.63	88.67	78.5	18	9.88	76.66	63.1	9.13	65.53	49.9	18
19	11.49	103.68	99.3	10.74	90.56	81.0	19	9.99	78.33	65.2	9.24	66.98	51.5	19
20	11.61	105.83	102.4	10.85	92.47	83.6	20	10.09	80.01	67.3	9.34	68.45	53.3	20
21	11.73	108.01	105.6	10.96	94.40	86.3	21	10.20	81.71	69.5	9.44	69.94	55.0	21
22	11.85	110.21	108.8	11.08	96.36	88.9	22	10.31	83.43	71.7	9.54	71.44	56.8	22
23	11.96	112.44	112.1	11.19	98.33	91.7	23	10.41	85.17	73.9	9.64	72.96	58.6	23
24	12.08	114.68	115.5	11.30	100.32	94.5	24	10.52	86.93	76.2	9.74	74.49	60.5	24
25	12.20	116.95	118.9	11.41	102.34	97.3	25	10.63	88.70	78.6	9.84	76.04	62.3	25
26	12.32	119.24	122.4	11.53	104.37	100.3	26	10.73	90.49	80.9	9.94	77.60	64.3	26
27	12.44	121.55	126.0	11.64	106.42	103.2	27	10.84	92.30	83.4	10.04	79.18	66.3	27
28	12.56	123.88	129.7	11.75	108.49	106.3	28	10.95	94.13	85.9	10.14	80.78	68.3	28
29	12.68	126.24	133.4	11.87	110.59	109.4	29	11.05	95.97	88.4	10.24	82.39	70.3	29
30	12.80	128.62	137.2	11.98	112.70	112.5	30	11.16	97.84	91.0	10.34	84.02	72.4	30
31	12.92	131.02	141.0	12.09	114.83	115.7	31	11.27	99.72	93.6	10.44	85.67	74.6	31
32	13.03	133.44	144.9	12.20	116.99	119.0	32	11.37	101.61	96.3	10.54	87.33	76.7	32
33	13.15	135.88	148.9	12.32	119.16	122.3	33	11.48	103.53	99.1	10.65	89.00	79.0	33
34	13.27	138.35	153.0	12.43	121.35	125.7	34	11.59	105.47	101.8	10.75	90.69	81.2	34
35	13.39	140.84	157.2	12.54	123.56	129.2	35	11.69	107.42	104.7	10.85	92.40	83.5	35
36	13.51	143.35	161.4	12.66	125.80	132.7	36	11.80	109.39	107.6	10.95	94.13	85.9	36
37	13.63	145.89	165.7	12.77	128.05	136.3	37	11.91	111.38	110.5	11.05	95.87	88.3	37
38	13.75	148.44	170.1	12.88	130.32	139.9	38	12.02	113.38	113.5	11.15	97.62	90.7	38
39	13.87	151.02	174.5	12.99	132.62	143.6	39	12.12	115.41	116.6	11.25	99.40	93.2	39
40	13.99	153.62	179.0	13.11	134.93	147.4	40	12.23	117.45	119.7	11.35	101.18	95.7	40
41	14.10	156.24	183.6	13.22	137.26	151.2	41	12.34	119.51	122.9	11.45	102.99	98.3	41
42	14.22	158.89	188.3	13.33	139.61	155.1	42	12.44	121.59	126.1	11.55	104.81	100.9	42
43	14.34	161.55	193.1	13.45	141.99	159.1	43	12.55	123.68	129.3	11.65	106.64	103.6	43
44	14.46	164.24	197.9	13.56	144.38	163.1	44	12.66	125.80	132.7	11.75	108.49	106.3	44
45	14.58	166.95	202.8	13.67	146.79	167.2	45	12.76	127.93	136.1	11.85	110.36	109.0	45
46	14.70	169.69	207.8	13.78	149.23	171.4	46	12.87	130.08	139.5	11.95	112.25	111.8	46
47	14.82	172.44	212.9	13.90	151.68	175.7	47	12.98	132.25	143.0	12.06	114.15	114.7	47
48	14.94	175.22	218.1	14.01	154.15	180.0	48	13.08	134.43	146.6	12.16	116.06	117.6	48
49	15.06	178.02	223.3	14.12	156.64	184.3	49	13.19	136.63	150.2	12.26	117.99	120.5	49
50	15.17	180.04	228.7	14.24	159.16	188.8	50	13.30	138.86	153.9	12.36	119.94	123.5	50
51	15.29	183.69	234.1	14.35	161.69	193.3	51	13.40	141.09	157.6	12.46	121.90	126.6	51
52	15.41	186.55	239.6	14.46	164.24	197.9	52	13.51	143.35	161.4	12.56	123.88	129.7	52
53	15.53	189.44	245.2	14.57	166.81	202.6	53	13.62	145.63	165.2	12.66	125.88	132.8	53
54	15.65	192.35	250.9	14.69	169.41	207.3	54	13.72	147.92	169.2	12.76	127.89	136.0	54
55	15.77	195.28	256.6	14.80	172.02	212.1	55	13.83	150.23	173.1	12.86	129.92	139.2	55

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

85 ft. 85 ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
56	15.89	198.24	262.5	14.91	174.65	217.0	56	13.94	152.56	177.2	12.96	131.96	142.5	56
57	16.01	201.22	268.4	15.03	177.30	222.0	57	14.04	154.91	181.3	13.06	134.02	145.9	57
58	16.13	204.22	274.4	15.14	179.98	227.0	58	14.15	157.27	185.5	13.16	136.09	149.3	58
59	16.24	207.24	280.5	15.25	182.67	232.2	59	14.26	159.65	189.7	13.26	138.18	152.7	59
60	16.36	210.28	286.7	15.36	185.38	237.3	60	14.36	162.05	194.0	13.36	140.29	156.2	60
61	16.48	213.35	293.0	15.48	188.12	242.6	61	14.47	164.47	198.3	13.47	142.41	159.8	61
62	16.60	216.44	299.4	15.59	190.87	248.0	62	14.58	166.91	202.8	13.57	144.55	163.4	62
63	16.72	219.55	305.9	15.70	193.64	253.4	63	14.68	169.36	207.2	13.67	146.71	167.1	63
64	16.84	222.68	312.5	15.81	196.43	258.9	64	14.79	171.83	211.8	13.77	148.88	170.8	64
65	16.96	225.83	319.1	15.93	199.25	264.5	65	14.90	174.32	216.4	13.87	151.06	174.6	65
66	17.08	229.01	325.9	16.04	202.08	270.1	66	15.00	176.83	221.1	13.97	153.27	178.4	66
67	17.19	232.21	332.7	16.15	204.93	275.9	67	15.11	179.36	225.9	14.07	155.48	182.3	67
68	17.31	235.43	339.7	16.27	207.80	281.7	68	15.22	181.90	230.7	14.17	157.72	186.2	68
69	17.43	238.68	346.7	16.38	210.70	287.6	69	15.33	184.46	235.6	14.27	159.97	190.2	69
70	17.55	241.94	353.9	16.49	213.61	293.6	70	15.43	187.04	240.5	14.37	162.23	194.3	70
71	17.67	245.23	361.1	16.60	216.54	299.6	71	15.54	189.64	245.6	14.47	164.52	198.4	71
72	17.79	248.54	368.4	16.72	219.49	305.8	72	15.65	192.25	250.7	14.57	166.81	202.6	72
73	17.91	251.87	375.9	16.83	222.47	312.0	73	15.75	194.88	255.8	14.67	169.13	206.8	73
74	18.03	255.23	383.4	16.94	225.46	318.3	74	15.86	197.54	261.1	14.78	171.46	211.1	74
75	18.15	258.60	391.0	17.06	228.47	324.7	75	15.97	200.20	266.4	14.88	173.80	215.5	75
76	18.26	262.00	398.8	17.17	231.50	331.2	76	16.07	202.89	271.8	14.98	176.17	219.9	76
77	18.38	265.42	406.6	17.28	234.56	337.8	77	16.18	205.60	277.2	15.08	178.54	224.3	77
78	18.50	268.87	414.6	17.39	237.63	344.4	78	16.29	208.32	282.7	15.18	180.94	228.9	78
79	18.62	272.33	422.6	17.51	240.72	351.2	79	16.39	211.06	288.3	15.28	183.35	233.4	79
80	18.69	274.29	427.2	17.57	242.56	355.2	80	16.46	212.78	291.9	15.35	184.95	236.5	80
81	18.75	276.26	431.8	17.64	244.41	359.3	81	16.53	214.52	295.4	15.41	186.57	239.6	81
82	18.82	278.23	436.4	17.71	246.27	363.4	82	16.59	216.25	299.0	15.48	188.19	242.8	82
83	18.89	280.21	441.1	17.77	248.13	367.5	83	16.66	218.00	302.7	15.55	189.82	245.9	83
84	18.96	282.20	445.8	17.84	250.00	371.7	84	16.73	219.75	306.3	15.61	191.46	249.1	84
85	19.02	284.19	450.5	17.91	251.88	375.9	85	16.79	221.51	310.0	15.68	193.10	252.3	85

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

90 ft. 90 ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.35	68.61	53.4	8.70	59.51	43.2	1	8.06	51.07	34.3	7.42	43.24	26.7	1
2	9.46	70.32	55.4	8.81	61.02	44.8	2	8.17	52.42	35.7	7.52	44.39	27.8	2
3	9.58	72.05	57.5	8.92	62.55	46.5	3	8.28	53.79	37.1	7.62	45.56	28.9	3
4	9.69	73.80	59.6	9.03	64.10	48.3	4	8.38	55.18	38.5	7.72	46.75	30.1	4
5	9.81	75.57	61.8	9.14	65.67	50.0	5	8.49	56.59	40.0	7.81	47.95	31.2	5
6	9.92	77.36	64.0	9.25	67.25	51.9	6	8.59	58.01	41.5	7.91	49.17	32.4	6
7	10.04	79.17	66.2	9.36	68.86	53.7	7	8.70	59.45	43.1	8.01	50.40	33.6	7
8	10.16	81.00	68.6	9.47	70.49	55.6	8	8.81	60.91	44.7	8.11	51.65	34.9	8
9	10.27	82.86	70.9	9.58	72.13	57.6	9	8.91	62.39	46.3	8.21	52.91	36.2	9
10	10.39	84.73	73.3	9.69	73.80	59.6	10	9.02	63.88	48.1	8.31	54.19	37.5	10
11	10.50	86.63	75.8	9.80	75.48	61.7	11	9.12	65.39	49.7	8.40	55.48	38.9	11
12	10.62	88.55	78.3	9.91	77.18	63.8	12	9.23	66.92	51.5	8.50	56.79	40.2	12
13	10.73	90.48	80.9	10.02	78.90	65.9	13	9.34	68.47	53.3	8.60	58.11	41.7	13
14	10.85	92.44	83.6	10.13	80.64	68.1	14	9.44	70.04	55.1	8.70	59.45	43.1	14
15	10.96	94.42	86.3	10.24	82.40	70.3	15	9.55	71.62	57.0	8.80	60.81	44.6	15
16	11.08	96.42	89.0	10.35	84.14	72.6	16	9.66	73.22	58.9	8.90	62.18	46.1	16
17	11.20	98.45	91.8	10.46	85.97	75.0	17	9.76	74.84	60.9	9.00	63.56	47.7	17
18	11.31	100.49	94.7	10.57	87.79	77.3	18	9.87	76.47	62.9	9.09	64.96	49.2	18
19	11.43	102.55	97.7	10.68	89.62	79.8	19	9.97	78.13	64.9	9.19	66.38	50.9	19
20	11.54	104.64	100.6	10.79	91.48	82.3	20	10.08	79.80	67.0	9.29	67.81	52.5	20
21	11.66	106.74	103.7	10.90	93.35	84.8	21	10.19	81.49	69.2	9.39	69.25	54.2	21
22	11.77	108.87	106.8	11.01	95.24	87.4	22	10.29	83.19	71.5	9.49	70.71	55.9	22
23	11.89	111.02	110.0	11.12	97.15	90.0	23	10.40	84.92	73.6	9.59	72.19	57.7	23
24	12.00	113.19	113.2	11.23	99.08	92.7	24	10.50	86.66	75.9	9.69	73.68	59.5	24
25	12.12	115.38	116.5	11.34	101.03	95.5	25	10.61	88.42	78.2	9.78	75.19	61.3	25
26	12.24	117.59	119.9	11.45	103.00	98.3	26	10.72	90.20	80.5	9.88	76.71	63.2	26
27	12.35	119.82	123.3	11.56	104.98	101.1	27	10.82	91.99	83.0	9.98	78.25	65.1	27
28	12.47	122.07	126.8	11.67	106.99	104.1	28	10.93	93.80	85.4	10.08	79.80	67.0	28
29	12.58	124.35	130.4	11.78	109.01	107.0	29	11.03	95.63	87.9	10.18	81.37	69.0	29
30	12.70	126.64	134.0	11.89	111.05	110.0	30	11.14	97.48	90.5	10.28	82.95	71.0	30
31	12.81	128.96	137.7	12.00	113.12	113.1	31	11.25	99.35	93.1	10.38	84.55	73.1	31
32	12.93	131.30	141.5	12.11	115.20	116.3	32	11.35	101.23	95.8	10.47	86.16	75.2	32
33	13.05	133.65	145.3	12.22	117.30	119.5	33	11.46	103.13	98.5	10.57	87.79	77.3	33
34	13.16	136.03	149.2	12.33	119.42	122.7	34	11.57	105.05	101.2	10.67	89.43	79.5	34
35	13.28	138.43	153.2	12.44	121.56	126.0	35	11.67	106.99	104.1	10.77	91.09	81.8	35
36	13.39	140.85	157.2	12.55	123.71	129.4	36	11.78	108.94	106.9	10.87	92.77	84.0	36
37	13.51	143.29	161.3	12.66	125.89	132.8	37	11.88	110.91	109.8	10.97	94.46	86.3	37
38	13.62	145.76	165.5	12.77	128.08	136.3	38	11.99	112.90	112.8	11.07	96.16	88.7	38
39	13.74	148.24	169.7	12.88	130.30	139.9	39	12.10	114.91	115.8	11.16	97.88	91.1	39
40	13.85	150.75	174.0	12.99	132.53	143.5	40	12.20	116.93	118.9	11.26	99.62	93.5	40
41	13.97	153.27	178.4	13.10	134.78	147.1	41	12.31	118.98	122.0	11.36	101.37	96.0	41
42	14.09	155.82	182.9	13.21	137.05	150.9	42	12.41	121.04	125.2	11.46	103.13	98.5	42
43	14.20	158.39	187.4	13.32	139.34	154.7	43	12.52	123.12	128.5	11.56	104.91	101.0	43
44	14.32	160.97	192.0	13.43	141.65	158.5	44	12.63	125.21	131.7	11.66	106.71	103.7	44
45	14.43	163.58	196.7	13.54	143.98	162.5	45	12.73	127.32	135.1	11.75	108.52	106.3	45
46	14.55	166.21	210.5	13.65	146.33	166.4	46	12.84	129.45	138.5	11.85	110.35	109.0	46
47	14.66	168.87	206.3	13.76	148.69	170.5	47	12.94	131.60	142.0	11.95	112.19	111.7	47
48	14.78	171.54	211.3	13.87	151.08	174.6	48	13.05	133.77	145.5	12.05	114.05	114.5	48
49	14.89	174.23	216.3	13.98	153.48	178.8	49	13.16	135.95	149.1	12.15	115.92	117.4	49
50	15.01	176.95	221.3	14.09	155.90	183.0	50	13.26	138.16	152.7	12.25	117.81	120.2	50
51	15.13	179.68	226.5	14.20	158.34	187.4	51	13.37	140.37	156.4	12.35	119.71	123.2	51
52	15.24	182.44	231.7	14.31	160.80	191.7	52	13.48	142.61	160.1	12.44	121.63	126.1	52
53	15.36	185.22	237.0	14.42	163.28	196.2	53	13.58	144.87	164.0	12.54	123.56	129.2	53
54	15.47	188.01	242.4	14.53	165.78	200.7	54	13.69	147.14	167.8	12.64	125.51	132.2	54
55	15.59	190.83	247.9	14.64	168.30	205.3	55	13.79	149.43	171.8	12.74	127.48	135.3	55

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress – 8000 psi

90 ft. 90 ft.

	Class H1			Class 1				Class 2			Class 3			
Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dia. (in.)	Area (sq. in.)	Moment (ft-k)	Dist. (ft.)
56	15.70	193.67	253.4	14.75	170.84	210.0	56	13.90	151.74	175.8	12.84	129.45	138.5	56
57	15.82	196.54	259.1	14.86	173.39	214.7	57	14.01	154.06	179.8	12.94	131.45	141.7	57
58	15.93	199.42	264.8	14.97	175.96	219.5	58	14.11	156.41	183.9	13.04	133.46	145.0	58
59	16.05	202.32	270.6	15.08	178.56	224.4	59	14.22	158.77	188.1	13.13	135.48	148.3	59
60	16.17	205.25	276.5	15.19	181.17	229.3	60	14.32	161.14	192.4	13.23	137.52	151.7	60
61	16.28	208.19	282.5	15.30	183.80	234.3	61	14.43	163.54	196.7	13.33	139.58	155.1	61
62	16.40	211.16	288.5	15.41	186.45	239.4	62	14.54	165.95	201.0	13.43	141.65	158.5	62
63	16.51	214.14	294.7	15.52	189.12	244.6	63	14.64	168.39	205.5	13.53	143.74	162.0	63
64	16.63	217.15	300.9	15.63	191.81	249.8	64	14.75	170.84	210.0	13.63	145.84	165.6	64
65	16.74	220.18	307.2	15.74	194.52	255.1	65	14.85	173.30	214.5	13.73	147.95	169.2	65
66	16.86	223.23	313.6	15.85	197.24	260.5	66	14.96	175.79	219.2	13.82	150.09	172.9	66
67	16.97	226.30	320.1	15.96	199.99	265.9	67	15.07	178.29	223.9	13.92	152.23	176.6	67
68	17.09	229.40	326.7	16.07	202.75	271.5	68	15.17	180.81	228.6	14.02	154.40	180.4	68
69	17.21	232.51	333.4	16.18	205.53	277.1	69	15.28	183.35	233.4	14.12	156.57	184.2	69
70	17.32	235.64	340.1	16.29	208.34	282.8	70	15.38	185.90	238.3	14.22	158.77	188.1	70
71	17.44	238.80	347.0	16.40	211.16	288.5	71	15.49	188.47	243.3	14.32	160.97	192.0	71
72	17.55	241.97	353.9	16.51	214.00	294.4	72	15.60	191.07	248.3	14.41	163.20	196.0	72
73	17.67	245.17	361.0	16.62	216.86	300.3	73	15.70	193.67	253.4	14.51	165.44	200.1	73
74	17.78	248.39	368.1	16.73	219.73	306.3	74	15.81	196.30	258.6	14.61	167.69	204.2	74
75	17.90	251.63	375.3	16.84	222.63	312.4	75	15.92	198.94	263.9	14.71	169.96	208.3	75
76	18.01	254.89	382.6	16.95	225.55	218.5	76	16.02	201.61	269.2	14.81	172.24	212.6	76
77	18.13	258.17	390.1	17.06	228.48	324.7	77	16.13	204.28	274.6	14.91	174.54	216.8	77
78	18.25	261.47	397.6	17.17	231.43	331.1	78	16.23	206.98	280.0	15.01	176.86	221.2	78
79	18.36	264.79	405.2	17.28	234.41	337.5	79	16.34	209.70	285.5	15.10	179.19	225.5	79
80	18.48	268.14	412.9	17.39	237.40	343.9	80	16.45	212.43	291.1	15.20	181.53	230.0	80
81	18.59	271.50	420.7	17.50	240.41	350.5	81	16.55	215.18	296.8	15.30	183.89	234.5	81
82	18.71	274.89	428.6	17.61	243.44	357.2	82	16.66	217.95	302.5	15.40	186.27	239.0	82
83	18.82	278.30	436.6	17.72	246.49	363.9	83	16.76	220.73	308.4	15.50	188.66	243.7	83
84	18.94	281.72	444.6	17.83	249.55	370.7	84	16.87	223.53	314.3	15.60	191.07	248.3	84
85	19.01	283.72	449.4	17.89	451.43	374.9	85	16.94	225.31	318.0	15.66	192.71	251.5	85
86	19.07	285.72	454.1	17.96	253.31	379.1	86	17.00	227.09	321.8	15.73	194.35	254.8	86
87	19.14	287.72	458.9	18.03	255.20	383.4	87	17.07	228.88	325.6	15.80	196.01	258.0	87
88	19.21	289.73	463.7	18.09	257.10	387.6	88	17.14	230.67	329.4	15.86	197.67	261.3	88
89	19.27	291.76	468.6	18.16	259.00	391.9	89	17.20	232.48	333.3	15.93	199.34	264.6	89
90	19.34	293.78	473.5	18.23	260.91	396.3	90	17.27	234.29	337.2	16.00	201.02	268.0	90

MOMENT REDUCTION DUE TO A BOLT HOLE IN A POLE

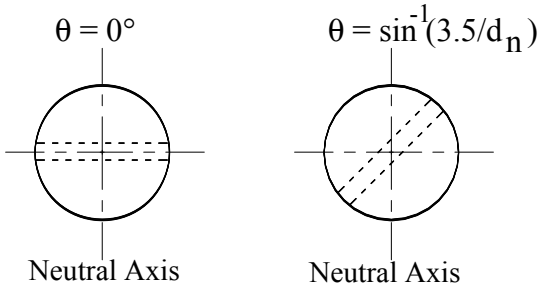
The reduction in moment capacity of a pole caused by a bolt hole is calculated by the equation:

$$M_{bh} = \frac{(F_b(b)(b^2 \sin^2\theta + d_n{}^2 \cos^2\theta)}{72(1000)}$$

where:

F_b	=	Ultimate fiber stress of the wood (psi)
d_n	=	Pole diameter at location 'n' (inches)
b	=	Width of hole, taken as bolt diameter plus 1/16 inch (inches)
M_{bh}	=	Reduction in strength (ft-kips)

The drawings below explain the Pole Moment Reduction table which follows:



The Pole Moment Reduction table which follows is based on 1000 psi for the fiber stress. For any species of wood, this number should be multiplied by the fiber stress of the wood divided by 1000.

TABLE F-4
POLE MOMENT (ft-k) REDUCTION
DUE TO BOLT HOLES FOR 1000 psi FIBER STRESS

POLE	3/4 in. *		7/8 in. *		1 in. *	
DIAM	0 DEGREES	THETA	0 DEGREES	THETA	0 DEGREES	THETA
9	0.914	0.78	1.055	0.897	1.195	1.017
9.1	0.934	0.93	1.078	1.078	1.222	1.222
9.2	0.955	0.96	1.102	1.102	1.249	1.249
9.3	0.976	0.98	1.126	1.126	1.276	1.276
9.4	0.997	1.00	1.151	1.151	1.304	1.304
9.5	1.018	1.02	1.175	1.175	1.332	1.332
9.6	1.040	1.04	1.200	1.200	1.360	1.360
9.7	1.062	1.06	1.225	1.225	1.388	1.388
9.8	1.084	1.08	1.251	1.251	1.417	1.417
9.9	1.106	1.11	1.276	1.276	1.446	1.446
10	1.128	1.13	1.302	1.302	1.476	1.476
10.1	1.151	1.15	1.328	1.328	1.505	1.505
10.2	1.174	1.17	1.355	1.355	1.535	1.535
10.3	1.197	1.20	1.381	1.381	1.566	1.566
10.4	1.221	1.22	1.408	1.408	1.596	1.596
10.5	1.244	1.24	1.436	1.436	1.627	1.627
10.6	1.268	1.27	1.463	1.463	1.658	1.658
10.7	1.292	1.29	1.491	1.491	1.690	1.690
10.8	1.316	1.32	1.519	1.519	1.721	1.721
10.9	1.341	1.34	1.547	1.547	1.753	1.753
11	1.365	1.37	1.576	1.576	1.786	1.786
11.1	1.390	1.39	1.604	1.604	1.818	1.818
11.2	1.416	1.42	1.633	1.633	1.851	1.851
11.3	1.441	1.44	1.663	1.663	1.884	1.884
11.4	1.467	1.47	1.692	1.692	1.918	1.918
11.5	1.492	1.49	1.722	1.722	1.952	1.952
11.6	1.518	1.52	1.752	1.752	1.986	1.986
11.7	1.545	1.54	1.782	1.782	2.020	2.020
11.8	1.571	1.57	1.813	1.813	2.055	2.055
11.9	1.598	1.60	1.844	1.844	2.090	2.090
12	1.625	1.63	1.875	1.875	2.125	2.125
12.1	1.652	1.65	1.906	1.906	2.161	2.161
12.2	1.680	1.68	1.938	1.938	2.196	2.196
12.3	1.707	1.71	1.970	1.970	2.233	2.233
12.4	1.735	1.74	2.002	2.002	2.269	2.269
12.5	1.763	1.76	2.035	2.035	2.306	2.306
12.6	1.792	1.79	2.067	2.067	2.343	2.343
12.7	1.820	1.82	2.100	2.100	2.380	2.380
12.8	1.849	1.85	2.133	2.133	2.418	2.418
12.9	1.878	1.88	2.167	2.167	2.456	2.456
13	1.907	1.91	2.201	2.201	2.494	2.494
13.1	1.937	1.94	2.235	2.235	2.532	2.532
13.2	1.966	1.97	2.269	2.269	2.571	2.571
13.3	1.996	2.00	2.303	2.303	2.610	2.610
13.4	2.026	2.03	2.338	2.338	2.650	2.650
13.5	2.057	2.06	2.373	2.373	2.689	2.689
13.6	2.087	2.09	2.408	2.408	2.729	2.729
13.7	2.118	2.12	2.444	2.444	2.770	2.770
13.8	2.149	2.15	2.480	2.480	2.810	2.810
13.9	2.180	2.18	2.516	2.516	2.851	2.851
14	2.212	2.21	2.552	2.552	2.892	2.892
14.1	2.244	2.24	2.589	2.589	2.934	2.934
14.2	2.275	2.28	2.626	2.626	2.976	2.976
14.3	2.308	2.31	2.663	2.663	3.018	3.018
14.4	2.340	2.34	2.700	2.700	3.060	3.060
14.5	2.373	2.37	2.738	2.738	3.103	3.103
14.6	2.405	2.41	2.776	2.776	3.146	3.146
14.7	2.439	2.44	2.814	2.814	3.189	3.189
14.8	2.472	2.47	2.852	2.852	3.232	3.232
14.9	2.505	2.51	2.891	2.891	3.276	3.276
15	2.539	2.54	2.930	2.930	3.320	3.320

*BOLT HOLE = BOLT DIAMETER + 1/16 in.

TABLE F-5
VOLUMES FOR DOUGLAS FIR AND
SOUTHERN YELLOW PINE POLES, (cu. ft.)

Height	Pole Classes			
ft.	H1	1	2	3
50	44.1	39.3	34.1	24.4
55	51.2	45.0	39.2	33.7
60	58.0	51.1	44.6	38.6
65	65.2	57.2	50.5	43.8
70	72.8	64.5	56.7	49.3
75	80.9	71.8	62.3	54.4
80	89.5	79.6	69.3	59.7
85	98.5	86.6	75.6	65.2
90	106.6	93.9	83.3	71.1

TALBE F-6
POLE WEIGHTS FOR DOUGLAS FIR (TREATED)
(50 pcf assumed) (lbs.)

Height	Pole Classes			
ft.	H1	1	2	3
50	2200	1970	1700	1220
55	2560	2250	1960	1690
60	2900	2560	2230	1930
65	3260	2860	2530	2190
70	3640	3225	2840	2470
75	4050	3590	3120	2720
80	4480	3980	3470	2990
85	4930	4330	3780	3260
90	5330	4700	4170	3560

TABLE F-7
POLE WEIGHTS FOR SOUTHERN YELLOW PINE (TREATED)
(60 pcf assumed) (lbs.)

Height	Pole Classes			
ft.	H1	1	2	3
50	2650	2360	2050	1470
55	3070	2700	2350	2020
60	3480	3070	2680	2320
65	3900	3430	3030	2630
70	4370	3870	3400	2960
75	4850	4300	3740	3260
80	5380	4780	4160	3580
85	5910	5200	4540	3910
90	6400	5630	5000	4270

APPENDIX G

CROSSARM DATA

- Moment Capacities of Standard Crossarms G-2
- Crossarm Loading Chart G-3

MOMENT CAPACITIES OF
STANDARD CROSSARM SIZES

The following table gives moment capacities ($M_{XX,}$ M_{YY}) of standard size crossarms for transmission structures in RUS Form 805. The moment capacities are based on the dressed size of the arms and a modulus of rupture of 7400 psi. M_{XX} is the moment resistance for vertical and M_{YY} is the moment resistance for longitudinal loads. Section moduli are also given for the respective axis.

TABLE G-1
CROSSARM SIZES AND MOMENT CAPACITIES

Crossarm Size	$S_{XX}(in^3)$	M_{XX}(ft-k)	$S_{YY}(in^3)$	M_{YY} (ft-k)
3-5/8 x 9-3/8	49.9	30.8	18.9	11.7
(2) 3-5/8 x 9-3/8	99.8	61.6	37.8	23.3
3-5/8 x 5-5/8	17.7	10.9	11.2	6.9
(2) 3-5/8 x 5-5/8	35.3	21.8	22.5	13.9
4-1/8 x 5-1/8	16.7	10.3	13.3	16.5
(2) 4-1/8 x 5-1/8	33.3	20.6	26.7	16.5
4-5/8 x 5-5/8	22.7	14.0	18.6	11.5
(2) 5/8 x 5-5/8	45.4	28.0	37.1	22.9
5-3.8 x 7-5/8	49.2	30.4	34.5	21.2
5-5/8 x 7-3/8	48.2	29.7	36.6	22.5

Example: Determine the maximum vertical span for a TSS-1L (69 kV)
Given: Conductor: 266.8 26/7 ACSR
Ldg. Dist: Heavy
Cond. Wt. (w_c): 1.0776 lbs./ft.
Insulator wt. (W_i): 51 lbs.
Moment arm(s): 5.5 ft.

Procedure: Moment capacity of TSS-1L arm (4-5/8" x 5-5/8") is 14.0 ft-k.

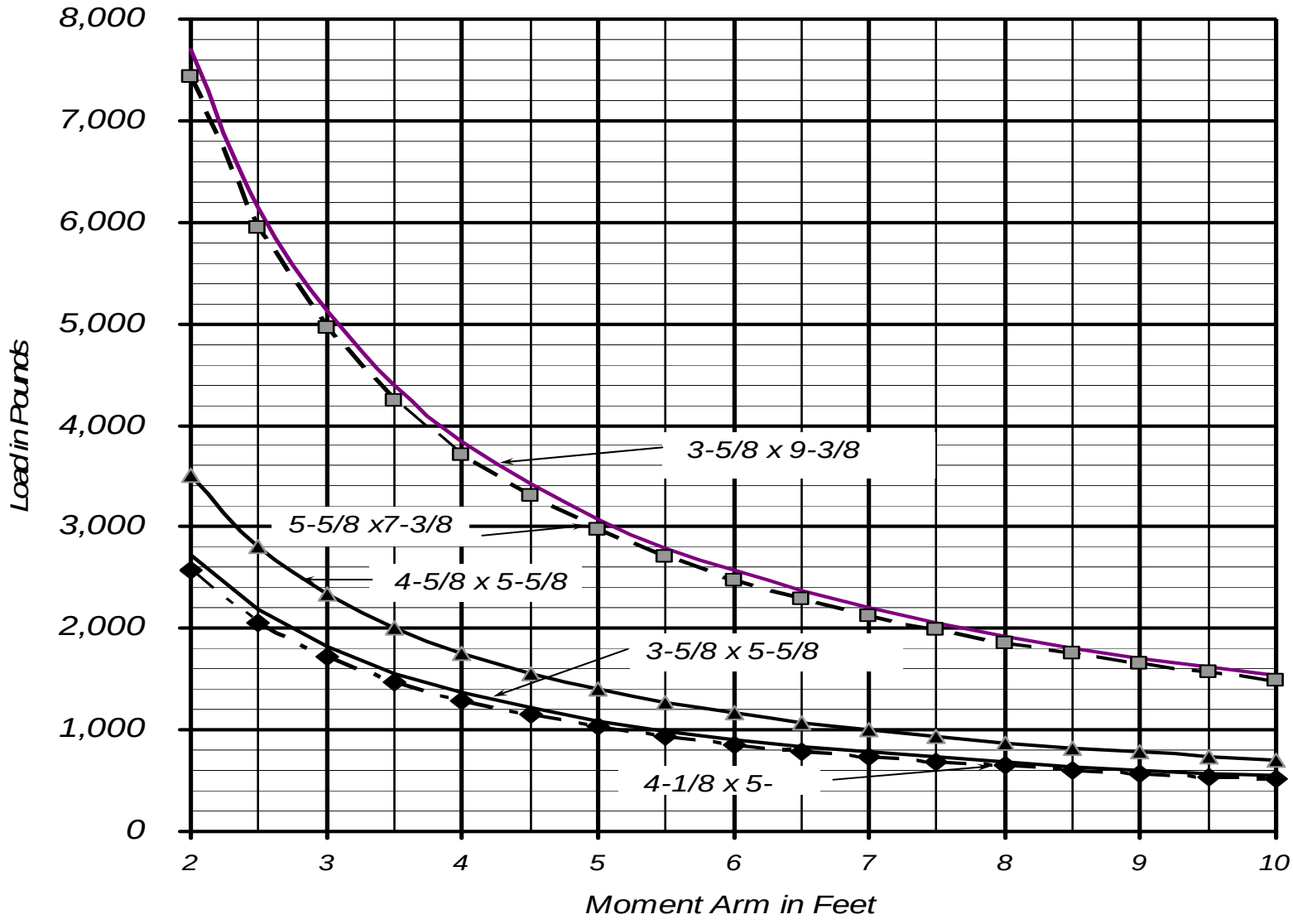
$$V.S. = \frac{\phi M_a - (OLF)\ (W_i)\ (s)}{(OLF)\ (W_c)\ (s)}$$

$$= \frac{(0.50)(14{,}000) - 1.5(51)\ (5.5)}{(1.5)\ (1.0776)(5.5)}$$

$$= 740\ ft.$$

FIGURE G-1

Crossarm Loading Chart - Maximum Permitted Vertical Loads of Various Sizes of Douglas Fir Crossarms (A fiber stress of 7400 x 0.5 or 3700 psi is assumed)



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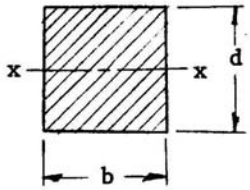
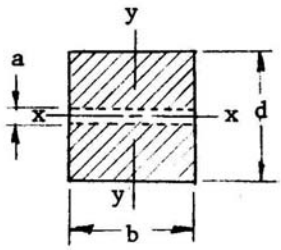
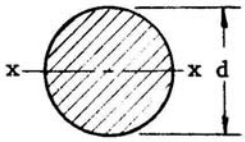
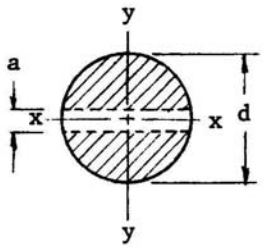
APPENDIX H

MISCELLANEOUS STRUCTURAL DATA

- Properties of Common Sections H-2
- Curve for Locating Plane of Contra-flexure for Braced H-frame structures H-3
- Tensile Strength of Bolts H-4
- Rated Breaking Strength of Guy Wire H-4

TABLE H-1
PROPERTIES OF COMMON SECTIONS

A = area (in^2, cm^2)	I_{y-y} = moment of inertia about the y-y axis	S_{y-y} = section modulus about the y-y axis
I_{x-x} = moment of inertia about the x-x axis (in^4, cm^4)	S_{x-x} = section modulus about the x-x axis (in^3, cm^3)	r_{x-x} = radius of gyration of x-x axis (in., cm)

	$A = bd$ $I_{x-x} = \frac{bd^3}{12}$	$S_{x-x} = \frac{bd^2}{6}$ $r_{x-x} = \frac{d}{\sqrt{12}}$
	$A = b(d - a)$ $I_{x-x} = \frac{b(d^3 - a^3)}{12}$ $S_{x-x} = \frac{b(d^3 - a^3)}{6d}$	$r_{x-x} = \sqrt{\frac{d^2 + ad + a^2}{12}}$ $I_{y-y} = \frac{(d - a)(b)^3}{12}$ $S_{y-y} = \frac{(d - a)(b)^2}{6}$
	$A = \frac{\pi d^2}{4} = \pi R^2$ $I_{x-x} = \frac{\pi d^4}{64} = \frac{\pi R^4}{4}$	$S_{x-x} = \frac{\pi d^3}{32} = \frac{\pi R^3}{4}$ $r = \frac{d}{4} = \frac{R}{2}$
	$A = \frac{\pi d^2}{4} - da$ $I_{x-x} = \frac{\pi d^4}{64} - \frac{da^3}{12}$ $S_{x-x} = \frac{\pi d^3}{32} - \frac{da^2}{6}$	$I_{y-y} = \frac{\pi d^4}{64} - \frac{ad^3}{12}$ $S_{y-y} = \frac{\pi d^3}{32} - \frac{ad^2}{6}$

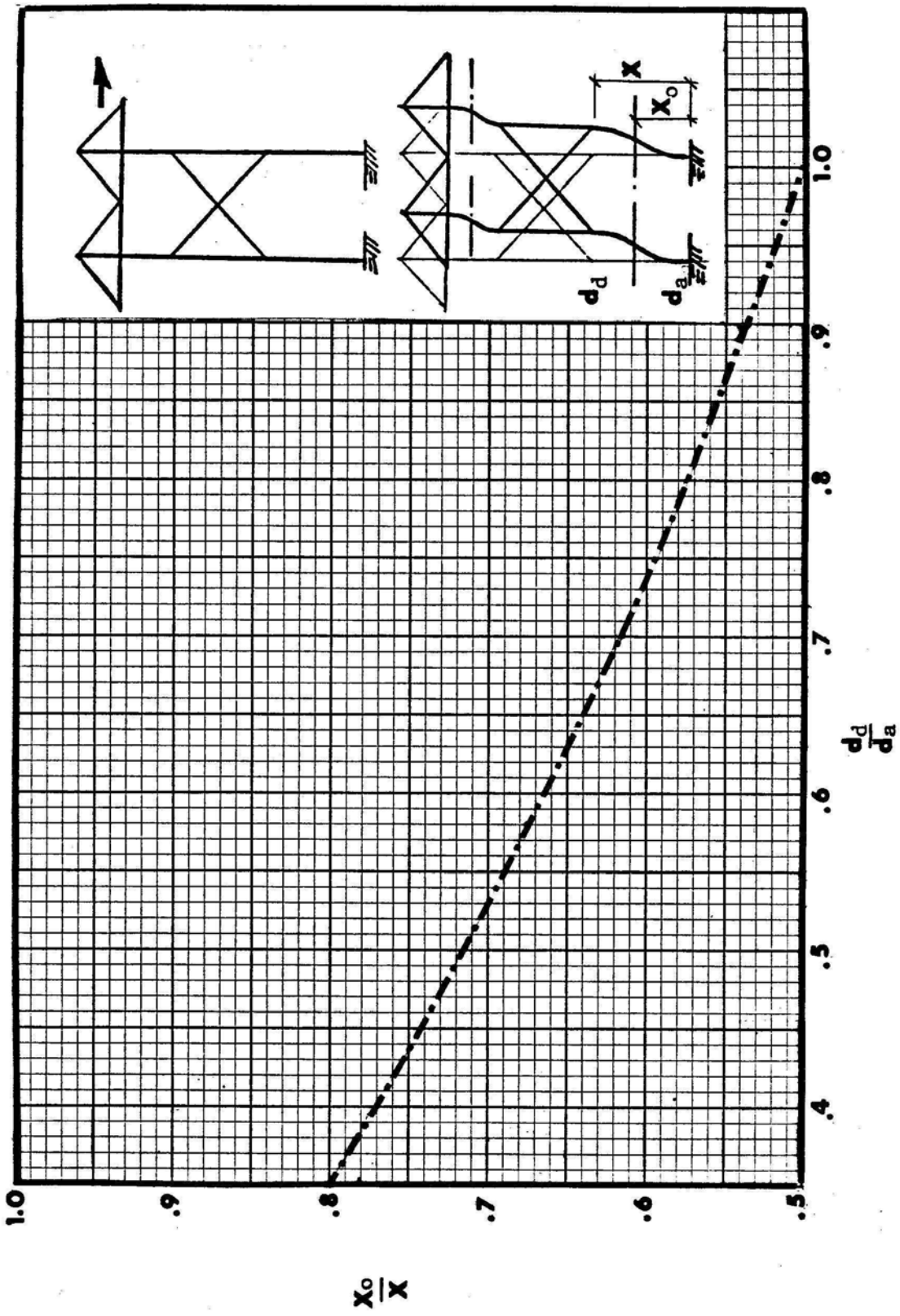


FIGURE H-1
CURVE FOR LOCATING PLANE OF CONTRAFLEXURE
IN X-BRACED H-FRAME STRUCTURES

TABLE H-2
STRENGTHS FOR MACHINE BOLTS
DOUBLE ARMING BOLTS, DOUBLE END BOLTS
(Conforming to ANSI C135.1)

Machine Bolt Diameter (in.)	Tension Stress Area ($in.^2$)	Min. Tensile Strength (lbs.)
1/2"	0.142	7,800
5/8"	0.226	12, 400
3/4"	0.334	18,350
7/8"	0.462	25,400
1"	0.606	33,500

TABLE H-3
STRENGTHS OF ASTM A325
HEAT TREATED, HIGH STRENGTH BOLTS

Machine Bolt Diameter (in.)	Tensile Stress Area (sq. in.)	Minimum Tensile Strength (lbs.)	Minimum Yield Strength (lbs.)
1/2	0.142	17,500	13,050
5/8	0.226	27,100	20,800
3/4	0.334	40,100	30,700
7/8	0.462	55,450	42,500
1	0.606	72,700	55,570

TABLE H-4
STRENGTH OF GUY STRANDS

Strand Size	Description	Minimum Breaking Strength (lbs)
3/8 in.	H.S.	10,800
7 No. 9 AWG	A.C.S	12,600
3/8 in.	E.H.S	14,400
7/16 in.	H.S.	14,500
7 No. 8 AWG	A.C.S	15,930
7 No. 7 AWG	A.C.S	19,060
7/16 in.	E.H.S	20,080

H.S.= high strength, E.H.S. = extra high strength, A.C.S.= aluminum clad steel

APPENDIX I
RI AND TVI

- Insulator and Hardware RIV Performance Values I-2
- Some Possible Sources of RI or RVI on Transmission Lines I-2
- Formulae for Calculating Surface Gradients of Conductors I-3
- Surface Gradient for Typical Designs I-5

INSULATOR AND HARDWARE RIV PERFORMANCE VALUES

The values below give recommended maximum RIV levels for insulators plus hardware assemblies for various voltages. The RIV values are measured using the procedure outlined in NEMA publication 107, *Methods of Measuring Radio Noise* – 1964.

TABLE I-1
RIV LEVELS

kV_{LL}	RIV Level in Microvolts at 1000 kH_{Z*}
34.5	100
46	200
69	200
115	200
138	200
161	500
230	500

Note:
The values in Table I-1 are from Figure 3 of "Transmission System Radio Influence"-IEEE Committee Report – Power Apparatus and System, August 1965. (This publication is the major work on the subject.)

SOME POSSIBLE SOURCES OF RI OR TVI ON TRANSMISSION LINES

1. Poor contact between metal parts of suspension insulators; an insufficient vertical span or an uplift condition can cause this.
2. Poor contact between clamps and clamp support brackets on clamp-top insulators;
3. Loose conductor clamps;
4. Loose hardware which can result from wood shrinkage, structure vibration or wind movement;
5. Loose crossarm braces or bolts;
6. Loose insulator mounting brackets;
7. Loose staples, bonding wire or ground wire;
8. Staples, bonding wire or ground wire too near ungrounded hardware;
9. Bond or ground wire clamped against wood under washer;
10. Unbonded guy wires too close to each other or to pole hardware;
11. Slack guy wire causing poor contact at pole attachments or at anchor eye;
12. Metal-to-metal clearance insufficient on pole hardware;
13. "Trash" on conductors (bits of wire, metal kite strings, tree limb, etc.).

FORMULAE FOR CALCULATING SURFACE GRADIENTS OF CONDUCTORS

Excessively high conductor surface gradients can result in radio noise, television interference, and corona. The equations below can be used to check the surface gradient. They are approximate but yield reasonably accurate results. They assume phase conductors that are far apart compared to their diameter.

Equation for Single Conductor per Phase**:**

$$g = \frac{kV_{LL}}{\sqrt{3}\ r\ \ell n\ \frac{D}{r}} \qquad \text{Eq. I-1}$$

where:

kV_{LL} = line-to-line voltage, kV
r = conductor radius, cm.
D = geometric mean distance (GMD) of the phase conductors, cm.
g = conductor surface gradient, kV/cm

Equation for Two Conductor Bundle per Phase**:**

$$g = \frac{kV_{LL}\,(1 + 2\ r/s)}{2\sqrt{3}\ r\ \ell n\ \frac{D}{\sqrt{rs}}} \qquad \text{Eq. I-2}$$

where:

All the symbols are the same as those above with the addition that:

s = the separation between subconductors, cm.

Application of Formulae**:**

It is recommended that transmission line designs that have unusually close phase spacing have the conductor surface gradient checked. A maximum conductor gradient of 16 kV/cm should be used.

Example

Determine the conductor gradient for a 230 kV line with (1) a 556.5 kcmil (dove) ACSR conductor and (2) a 1272 kcmil (pheasant) conductor. GMD for TH-230 is 24.57 feet or 784.90 cm.

556.5 kcmil conductor:

$$r = \frac{.927}{2}(2.54) = 1.18$$

$$g = \frac{230\ (1.05)}{\sqrt{3}\ (1.18)\ln\frac{748.90}{1.18}}$$

g = 18.3 kV/cm.

The 556.5 kcmil conductor should not be used for 230 kV lines.

1272 kcmil Conductor (1 Conductor):

$$r = \frac{1.382}{2}(2.54) = 1.755$$

$$g = - \ g = \frac{230\ (1.05)}{\sqrt{3}\ (1.755)\ln\frac{748.90}{1.755}}$$

g = 13.12 kV/cm.

TABLE I-2
SURFACE GRADIENT FOR TYPICAL DESIGNS

16 kV/cm recommended to minimize radio noise

				TP-3 GMD	TP-3 GMD	TS-1 GMD	TU-1AA GMD	TH-230 GMD
			(feet)	2.53	2.53	3.00	3.59	24.57
			(cm)	77.15	77.15	91.33	109.35	748.85
Conductor	**Diameter**	**Radius (inches)**	**Radius (cm)**	**Gradient (kV/cm) 34.5**	**Gradient (kV/cm) 46**	**Gradient (kV/cm) 69**	**Gradient (kV/cm) 161**	**Gradient (kV/cm) 230**
RAVEN	0.398	0.199	0.505	8.23	10.97	15.92	35.91	37.78
QUAIL	0.447	0.224	0.568	7.50	10.00	14.50	32.68	34.19
PIGEON	0.502	0.251	0.638	6.84	9.12	13.22	29.76	30.94
PENGUIN	0.563	0.282	0.715	6.25	8.33	12.06	27.14	28.04
WAXWING	0.609	0.305	0.773	5.88	7.83	11.33	25.49	26.22
PARTRIDGE	0.642	0.321	0.815	5.64	7.52	10.87	24.44	25.06
MERLIN	0.684	0.342	0.869	5.37	7.16	10.34	23.24	23.75
LINNET	0.721	0.361	0.916	5.15	6.87	9.93	22.29	22.70
ORIOLE	0.741	0.371	0.941	5.04	6.72	9.72	21.81	22.18
CHICKADEE	0.743	0.372	0.944	5.03	6.71	9.69	21.76	22.13
IBIS	0.783	0.392	0.994	4.83	6.44	9.31	20.88	21.17
LARK	0.806	0.403	1.024	4.73	6.30	9.10	20.41	20.65
PELICAN	0.814	0.407	1.034	4.69	6.25	9.03	20.25	20.48
FLICKER	0.846	0.423	1.074	4.55	6.07	8.76	19.65	19.82
HAWK	0.858	0.429	1.090	4.51	6.01	8.67	19.44	19.59
HEN	0.883	0.442	1.121	4.41	5.88	8.48	19.00	19.12
OSPREY	0.879	0.440	1.116	4.42	5.90	8.51	19.07	19.19
PARAKEET	0.914	0.457	1.161	4.29	5.72	8.25	18.50	18.57
DOVE	0.927	0.464	1.177	4.25	5.66	8.17	18.30	18.35
EAGLE	0.953	0.477	1.210	4.16	5.55	7.99	17.91	17.92
KINGBIRD	0.94	0.470	1.194	4.20	5.60	8.08	18.10	18.13
ROOK	0.977	0.489	1.241	4.08	5.44	7.84	17.56	17.55
GROSBEAK	0.99	0.495	1.257	4.04	5.39	7.76	17.38	17.36
EGRET	1.019	0.510	1.294	3.95	5.27	7.59	17.00	16.94

TABLE I-2 (Continued)
SURFACE GRADIENT FOR TYPICAL DESIGNS

16 kV/cm recommended to minimize radio noise				TP-3 GMD	TP-3 GMD	TS-1 GMD	TU-1AA GMD	TH-230 GMD
			(feet)	2.53	2.53	3.00	3.59	24.57
			(cm)	77.15	77.15	91.33	109.35	748.85
Conductor	**Diameter**	**Radius (inches)**	**Radius (cm)**	**Gradient (kV/cm) 34.5**	**Gradient (kV/cm) 46**	**Gradient (kV/cm) 69**	**Gradient (kV/cm) 161**	**Gradient (kV/cm) 230**
CUCKOO	1.092	0.546	1.387	3.75	5.00	7.20	16.11	15.98
DRAKE	1.108	0.554	1.407	3.71	4.95	7.12	15.93	15.79
MALLARD	1.14	0.570	1.448	3.63	4.84	6.97	15.59	15.41
TERN	1.063	0.532	1.350	3.83	5.11	7.35	16.45	16.35
CONDOR	1.093	0.547	1.388	3.75	5.00	7.20	16.10	15.97
RAIL	1.165	0.583	1.480	3.57	4.77	6.86	15.33	15.13
CARDINAL	1.196	0.598	1.519	3.51	4.67	6.72	15.03	14.80
BUNTING	1.302	0.651	1.654	3.29	4.39	6.31	14.08	13.79
GRACKLE	1.338	0.669	1.699	3.23	4.30	6.18	13.79	13.48
BITTERN	1.345	0.673	1.708	3.21	4.28	6.15	13.74	13.42
PHEASANT	1.382	0.691	1.755	3.15	4.20	6.03	13.46	13.12
LAPWING	1.502	0.751	1.908	2.96	3.95	5.67	12.64	12.24
FALCON	1.545	0.773	1.962	2.90	3.87	5.55	12.37	11.95
CHUKAR	1.602	0.801	2.035	2.83	3.77	5.40	12.04	11.60
BLUEBIRD	1.762	0.881	2.238	2.64	3.52	5.04	11.21	10.72

APPENDIX J

INSULATOR SWING TABLES

TABLE J-1
INSULATOR SWING VALUES FOR STANDARD TANGENT STRUCTURES
(Porcelain Insulators with Ball Hook and Suspension Clamp
per Drawing TM-1A. Insulator String Lengths per TABLE C-3)

Sturcture and Voltage	Number of Insulators	Insulator Swing Angle In Degrees (no wind clearance, note 1)	Insulator Swing Angle In Degrees (moderate wind clearance, note 2)	Insulator Swing Angle In Degrees (high wind clearance, note 3)
34.5 kV				
TS-1, TS-1X	3	40.2	69.8	82.0
TS-1L, TS-1LX	3	40.8	69.8	82.0
TS-2, TS-2X	3	40.2	70.5	82.3
TSD-1, TSD-1X,	3	25.3	52.3	68.0
TSD-2, TSD-2X	3	25.3	52.9	68.0
TS-9	3	67.9	92.9	108.6
TSS-1, TSS-2	3	40.8	72.5	89.5
TSS-1L	3	40.8	70.1	89.1
TSS-9	3	77.0	101.9	115.1
TSZ-1, TSZ-2	3	52.6	77.1	90.5
TH-1, TH-1G	3	41.3	72.9	89.8
TH-9, TH-9G	3	77.0	101.9	115.1
46 kV				
TS-1, TS-1X	3	40.2	64.5	82.0
TS-1L, TS-1LX	3	40.8	64.5	82.0
TS-2, TS-2X	3	40.2	65.0	82.3
TSD-1, TSD-1X	3	25.3	47.7	68.0
TSD-2, TSD-2X	3	25.3	48.0	68.0
TS-9	3	67.9	86.9	108.6
TSS-1, TSS-2	3	40.8	64.9	89.5
TSS-1L	3	40.8	64.9	89.5
TSS-9	3	77.0	97.2	115.1
TSZ-1, TSZ-2	3	52.6	72.3	90.5
TH-1, TH-1G	3	41.3	67.8	89.8
TH-9, TH-9G	3	77.0	97.2	115.1
69 kV				
TS-1, TS-1X	4	20.0	38.5	74.0
TS-1L, TS-1LX	4	33.5	53.5	74.0
TS-2, TS-2X	4	20.0	38.5	74.2
TSD-1, TSD-1X	4	17.8	38.5	62.8
TSD-2, TSD-2X	4	17.8	38.5	62.8
TS-9	4	45.8	71.7	93.2
TSS-1, TSS-2	4	25.9	45.8	85.4
TSS-1L	4	35.1	60.9	85.4
TSS-9	4	45.8	79.2	106.6

TABLE J-1 (Continued)
INSULATOR SWING VALUES FOR STANDARD TANGENT STRUCTURES
(Porcelain Insulators with Ball Hook and Suspension Clamp
per Drawing TM-1A. Insulator String Lengths per TABLE C-3)

Sturcture and Voltage	Number of Insulators	Insulator Swing Angle In Degrees (no wind clearance)	Insulator Swing Angle In Degrees (moderate wind clearance)	Insulator Swing Angle In Degrees (high wind clearance)
69 kV (continued)				
TSZ-1, TSZ-2	4	41.7	61.2	81.4
TH-1, TH-1G	4	35.6	61.2	85.6
TH-1B, TH-1BG	4	66.5	86.2	106.6
TH-1A,	4	35.6	61.2	85.6
TH-1AA, TH-1AAX	4	27.2	56.1	81.3
TS-115	4	33.7	60.0.	84.6
115 Kv				
TS-115	7	26.9	54.2	80.2
TH-1A	7	28.3	58.7	80.8
TH-1AA,TH-1AAX	7	22.1	55.5	78.1
TH-10 SERIES	7	22.1	55.5	78.1
138 kV				
TH-10 SERIES	8	19.9	54.5	77.2
161 kV				
TH-10 SERIES	10	16.4	50.5	77.7
230 kV				
TH-230	12	16.5	47.8	74.8
TH-230	13	15.2	43.9	76.0

Notes:

1. Conditions at which insulator swing no wind clearances are to be maintained follow (See Chapter 7 of this bulletin):
   - Wind: Assume no wind.
   - Temperature: Assume a temperature of 60°F.
2. Conditions at which insulator swing moderate wind clearances are to be maintained follow (See Chapter 7 of this bulletin):
   - Wind: Assume a wind of at least 6 psf blowing. A wind pressure values of no higher than 9 psf (60 mph) should be used for the moderate wind clearance design
   - Temperature: A temperature of no more than 32°F should be used for tangent and small angle structures where the insulator string is suspended from a crossarm. A lower temperature value should be used where such a temperature can be reasonably expected to occur in conjunction with the wind value assumed.
3. Conditions at which insulator swing high wind clearances are to be maintained follow (See Chapter 7 of this bulletin):
   - Wind: The minimum assumed wind value should be at least the 10-year mean recurrence interval. More wind may be assumed if deemed appropriate.
   - Temperature: The temperature assumed should be that temperature at which the wind is expected to occur. The conductor should be assumed to be at initial tension conditions.

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APPENDIX K
SYMBOLS AND ABBREVIATIONS

A	=	Cross sectional area	ft^2, in^2
A	=	Separation between points of insulator string for two phases	ft^2
A	=	Allowable separation at midspan	ft
A_U	=	Designated ultimate anchor capacity	lbs
B	=	Vertical separation at supports	ft
C	=	Clearance between a supply conductor and an object or ground. May be specified as C_1 C_2, C_3, etc.	in
C	=	Circumference of pole. Depending on the location, the circumference may be indicated as C_A, C_B C_C .	ft, in
D_e	=	Embedment depth	ft
D_v	=	Vertical separation between conductors	ft
E_C	=	Experience factor for horizontal separation requirements	
E	=	Experience factor for horizontal separation requirements. It is generally recommended that E be greater then 1.25.	
E	=	Modulus of elasticity of wood	psi
EI&W	=	Extreme Ice and Concurrent Wind	
F	=	Wind pressure on a cylindrical surface	psf
F_b	=	Designated ultimate bending stress for either the pole or the crossarm	psi
F_c	=	Experience factor to be used in horizontal separation requirements (Fc = 1.15 for light loading district, 1.2 for medium loading district, and 1.25 for heavy loading district).	
F_s	=	Designated ultimate skin friction of soil	psf
G, G_N	=	Calculated force in the guy, considering guy lead	lbs
G_U	=	Rated breaking strength of guy.	lbs
H	=	Horizontal separation between the phase conductors at the structure.	ft
HS	=	Horizontal span. For any structure the HS = $(L_1 + L_2)/2$ and is the horizontal distance between the midspan points of adjacent spans. The horizontal span times the wind force per foot on the conductor (p_c) will yield the total horizontal force per conductor on the structure.	ft
HS_N	=	For an H-frame structure, HS_A, HS_B, etc., are the horizontal spans limited by pole strength at locations on the pole.	ft
HS_R	=	Horizontal span limited by bearing	ft

APPENDIX K
SYMBOLS AND ABBREVIATIONS

HSx	=	Horizontal span as limited by crossbrace strength Of an H-frame structure	ft
I	=	Moment of inertia of a structural member	in^4
L	=	Span length or the horizontal distance from one structure to an adjacent structure. L_1, L_2, L_3, etc., are designations for difference spans.	ft
L_{avg}	=	Average span length	ft
L_{max}	=	Maximum span length	ft
LF	=	Load Factor	
LL	=	Loop length of conductor when vibrating	ft
M	=	Major axis of Lissagous ellipses	ft
M_a	=	Moment capacity of crossarms	ft.-lbs
M_g	=	Moment capacity of a pole at groundline	ft.-lbs
M_N	=	Moment capacity at the indicated location.	ft-lbs
M_{bh}	=	Moment capacity at the indicated location.	ft-lbs
M_{wp}	=	Moment due to wind on the pole.	ft-lbs
P	=	Horizontal force.	lbs
P_C	=	Force due to wind on conductors (plus ice, if any)	lbs
P_g	=	Force due to wind on OHGW (plus ice, if any)	lbs
P_t	=	Force due to wind on conductors and OHGW (plus ice)	lbs
P_{cr}	=	Critical buckling load for a member in compression	lbs
P-δ	=	P-delta moment, additional moment due to deflection	ft-lbs
R	=	Rise of a davit arm	ft
R	=	Total transverse load due to wind on the conductors and OHGW and wire tension load for conductors and OHGW	lbs
R_g	=	Total transverse load due to wind on the OHGW (P_g) and wire tension load for OHGW (T_g)	lbs
RS	=	Ruling Span	ft
S	=	Section modulus of a structural member equal I/c	in^3

APPENDIX K
SYMBOLS AND ABBREVIATIONS

S	=	Sag of conductor	ft
Se	=	Soil constant	
S_f	=	Final Sag of a bare conductor at condition specified	ft
Si	=	Sag of an iced conductor	ft
S_ℓ	=	Sag of the lower bare conductor	ft
$S_{i\ell}$	=	Sag of an iced lower conductor	ft
S_{RS}	=	Sag at midspan for a span equal to the ruling span	ft
S_u	=	Sag of an upper conductor	ft
S_{iu}	=	Sag of an iced upper conductor	ft
SP	=	Diagonal distance between phase conductors at structure	ft
T	=	Resultant tension at support	lbs
T_c	=	Average conductor tension	lbs
T_g	=	Average OHGW tension	lbs
T_h	=	Horizontal component of tension	lbs
T_{avg}	=	Average conductor tension in a span, ($T_{avg}=\frac{T_{h}+T}{2}$)	lbs
V	=	Wind velocity	miles/hr
V	=	Vertical separation between phase conductors at a structure	ft
VS	=	Vertical span, the horizontal distance between the maximum sag points of two adjacent spans. The vertical span times the weight of the loaded conductor per foot (W_c) will yield the vertical force per conductor.	ft
W	=	Weight	lbs
W	=	Right-of-way width	ft
W_c	=	Weight of conductors (plus ice, if any)	lbs
W_g	=	Weight of OHGW (plus ice, if any)	lbs
W_p	=	Weight of pole	lbs
Wi	=	Weight of insulators	lbs
V	=	Wind velocity	miles/hr
V	=	Vertical separation between phase conductors at a structure	ft

APPENDIX K
SYMBOLS AND ABBREVIATIONS

a	=	Length as indicated	ft
a	=	Insulator swing clearance for normal condition	in
b	=	Distance between two poles for an H-frame	ft
b	=	Bolt hole diameter; width of a section	in
b	=	Insulator swing clearance for 6 psf wind condition	in
c	=	Insulator swing clearance for high wind condition	in
c	=	Distance from the neutral axis to the extreme fiber	in
d_c	=	Diameter of conductor	in
d_g	=	Diameter of overhead ground wire	in
d_g	=	Diameter at the groundline of a pole	in
d_n	=	Diameter of a pole. Depending on the location the diameter may be indicated as da, db, dc, dd, , etc.	in
d_t	=	Diameter at the top of a pole	in
f	=	Frequency of conductor vibration	Hz
f_b	=	Computed bending stress	psi
a	=	Length as indicated	ft
a	=	Insulator swing clearance for normal condition	in
b	=	Distance between two poles for an H-frame	ft
b	=	Bolt hole diameter; width of a section	in
b	=	Insulator swing clearance for 6 psf wind condition	in
c	=	Insulator swing clearance for high wind condition	in
c	=	Distance from the neutral axis to the extreme fiber.	in
d_c	=	Diameter of conductor	in
d_g	=	Diameter of overhead ground wire	in
d_g	=	Diameter at the groundline of a pole.	in

APPENDIX K
SYMBOLS AND ABBREVIATIONS

d_n	=	Diameter of a pole. Depending on the location the diameter may be indicated as da, db, dc, dd, , etc.	in
d_t	=	Diameter at the top of a pole	in
f	=	Frequency of conductor vibration	Hz
f_b	=	Computed bending stress	psi
f_s	=	Computed skin friction of soil	psf
g	=	Acceleration due to gravity 9.81 (32.2)	ft/sec^2
g	=	Conductor surface gradient	
h_n	=	Length, may be indicated as h1, h2, h3, or ha, hb hc, etc.	ft.
kVL-G	=	Line to ground voltage	kV
kVL-L	=	Line to line voltage	kV
ℓ	=	Unbraced length used in buckling calculations	ft.
ℓ_i	=	Insulator string length	in. ft.
m_c	=	Mass per unit length of the conductor	lbm/ft.
m_g	=	Mass for unit length of the overhead ground wire	lbs./ft.
p_c	=	Horizontal force per unit length due to wind on the conductors (plus ice, if any)	lbs/ft.
p_g	=	Horizontal force per unit length due to wind on the overhead ground wire (plus ice, if any)	lbs/ft
p_t	=	Total horizontal force per unit length due to wind on the conductors and overhead ground wire	lbs/ft
q_a	=	Calculated allowable soil bearing capacity	psf
q_u	=	Calculated ultimate soil bearing capacity.	psf
r	=	Radius of gyration. a property of a cross section equal to $\sqrt{I / A}$.	lbs/ft
r	=	Radius of conductor	in.
r_c	=	Resultant load per unit length on conductor including ice and wind and K factor	lbs/ft

APPENDIX K
SYMBOLS AND ABBREVIATIONS

s	=	Maximum moment arm for a crossarm	ft.
w_c	=	Weight per unit length of the conductors (plus ice, if any)	lbs/ft.
w_g	=	Weight per unit length of the overhead ground wire (plus ice, if any)	lbs/ft.
x_n, y_n, z_n	=	Length. May be indicated as x_0, x_1, z_0, x_1, etc.	ft.

APPENDIX L
SELECTED SI-METRIC CONVERSIONS

AREA

To Convert From	To	Multiply by
circular mil (cmil)	square meter (m^2)	5.067075 E – 10
square centimeter (cm^2)	square meter (m^2)	*1.000 E – 04
square foot (ft^2)	square meter (m^2)	*9.290304 E – 02
square inch (in^2)	square meter (m^2)	*6.451600 E – 04
square kilometer (km^2)	square meter (m^2)	*1.000 E + 06
square mile (mi^2)	square meter (m^2)	2.589988 E + 06

FORCE

To Convert From	To	Multiply by
kilogram force (kgf)	newton (N)	*9.806650
Kip	newton (N)	4.448222 E + 03
pound force (lbf)	newton (N)	4.448222

FORCE PER LENGTH

To Convert From	To	Multiply by
kilogram force per meter (kgf/m)	newton per meter (N/m)	*9.806650
pound per foot (lb/ft)	newton per meter (N/m)	1.459390 E + 01

DENSITY

To Convert From	To	Multiply by
pound per cubic inch (lb/in^3)	kilogram per cubic meter (kg/m^3)	2.767990 E + 04
pound per cubic foot (lb/ft^3)	kilogram per cubic meter (kg/m^3)	1.601846 E + 01

LENGTH

To Convert From	To	Multiply by
foot (ft)	meter (m)	3.048 E – 01
inch (in)	meter (m)	*2.540 E – 02
kilometer (km)	meter (m)	*1.000 E + 03
mile (mi)	meter (m)	*1.609344 E + 03

*Exact Conversion.

SELECTED SI-METRIC CONVERSIONS (Continued)

LINEAR DENSITY

To Convert From	To	Multiply by
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488164
pound per inch (lb/in)	kilogram per meter (kg/m)	1.785797 E + 01

LOAD CONCENTRATION

To Convert From	To	Multiply by
pound per square inch (lb/in^2)	kilogram per square meter (kg/m^2)	7.03069 E + 02
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882428
ton per square foot (ton/ft^2)	kilogram per square meter (kg/m^2)	9.071847 E + 02

MASS

To Convert From	To	Multiply by
pound (avoirdupois) (lb)	kilogram (kg)	4.535924 E - 01

PRESSURE

To Convert From	To	Multiply by
kip per square inch (kip/in^2)	pascal (Pa)	6.894757 E + 06
kip per square foot (kip/ft^2)	pascal (Pa)	4.788026 E + 04
newton per square meter (N/m^2)	pascal (Pa)	*1.000
pound per square foot (lb/ft^2)	pascal (Pa)	4.788026 E + 04
pound per square inch (lb/in^2)	pascal (Pa)	6.894757 E + 03

BENDING MOMENT

To Convert From	To	Multiply by
kilogram force meter (kgf-m)	newton meter (N-m)	*9.806650
kip-foot (kip-ft)	newton meter (N-m)	1.355818
pound-foot (lb-ft)	newton meter (N-m)	1.355818

*Exact Conversion.

SELECTED SI-METRIC CONVERSIONS, (Continued)

VELOCITY

To Convert From	To	Multiply by
foot per second (ft/s)	meter per second (m/s)	*3.048 E - 01
kilometer per hour (km/h)	meter per second (m/s)	2.777778 E - 01
mile per hour (mi/h or mph)	meter per second (m/s)	4.470400 E - 01
meter per hour (m/h)	meter per second (m/s)	2.777778 E - 04

VOLUME

To Convert From	To	Multiply by
cubic foot (ft^3)	cubic meter (m^3)	2.831685 E - 02.
cubic inch (in^3)	cubic meter (m^3)	1.638706 E - 05
cubic kilometer (km^3)	cubic meter (m^3)	*1.000 E + 09
cubic millimeter (mm^3)	cubic meter (m^3)	*1.000 E - 09

TEMPERATURE

To Convert From	Degrees Fahrenheit **ºF**	Degrees Celsius **ºC**
XºC =	9/5 X + 32	----------
XºF =	----------	5/9(X – 32)

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